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October 2009

Increasing the Mobility of Dismounted Marines

Small Unit Mobility Enhancement Technologies: Unmanned Ground Vehicles Market Survey

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EXECUTIVE SUMMARY

In the Global War on Terror, particularly in Areas of Operation such as Afghanistan, there is an urgent need for a means of increasing the mobility of dismounted Marines in order to provide them with increased speed, lethality, and survivability in an inhospitable terrain. A promising avenue of inquiry is an investigation resulting in a market survey involving the rapidly-developing field of unmanned ground systems.

To this end, the Office of Naval Research (ONR) Expeditionary Maneuver Warfare and Combating Terrorism Department (ONR-30) commissioned the Unmanned Systems Branch (7171) of the Space and Naval Warfare Systems Center Pacific (SSC Pacific) to conduct a detailed survey and analysis of current and developing robotic technologies to support the Small Unit Mobility Enhancement Technologies (SUMET) strategy at ONR. The specific focus is on tactical unmanned ground systems capable of supporting an increase in the mobility of dismounted Marines operating in a tactical environment, lightening the load of the individual Marine, and possibly providing a logistical re-supply capability for small units.

The scope of this project was to conduct "an encyclopedic survey that will span the range of unmanned ground vehicles (UGVs), from the iRobot Packbot size up to the size of a Humvee." More than 500 systems were identified for evaluation against the ONR-specified criteria, and broad performance data were collected in seven categories for each of these systems.

Each of the systems was evaluated against the ONR-specified criteria and those that met minimum standards were rank-ordered according to a more complete list of performance criteria. The top 15 systems are profiled and discussed in Section IV.

Even among the top systems, the overall scores are comparatively modest, and each system has significant weaknesses involving one or more of the criteria. In fact, among the systems reviewed, no single system is "best-of-breed" across the board for all – or even most – of the performance criteria. Possible reasons for these results are discussed.

A number of recommendations are offered in terms of additional research objectives and design characteristics for the objective SUMET UGV and a "Way Forward" is offered with specific near-term recommendations. These include performing operational test and evaluation of the most promising existing systems, issuing RFPs (requests for proposals) involving an iteratively refined set of required technology capabilities, and commissioning a capable and trusted system integrator to begin to develop one or more prototypes using best-of-breed hardware and software components.

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SECTION I. INTRODUCTION

As the Global War on Terror (GWOT) continues to evolve from a largely urban fight in places such as Fallujah, Ramadi, and Baghdad, Iraq to more rural settings such as those of Afghanistan, tactical and logistical requirements similarly evolve. Invaded repeatedly over the centuries by the Persians, Greeks, Arabs, Mongols, Tartars, British, and Russians, Afghanistan's location and terrain have historically proven to be extremely challenging. With neighbors such as Iran, Pakistan, Turkmenistan, Uzbekistan, and Tajikistan, Afghanistan lives in a tough and inhospitable neighborhood, typically unsupportive of U.S. tactical or logistical requirements. Afghanistan has about a quarter-million square miles – and more than 50% of its total land area lies above 6,500 feet. Additionally, it has rolling desert, scattered salt flats, and numerous rivers. Summer high temperatures reach the low 90s, with winter lows hovering near freezing (and much colder in the higher elevations).

The inhospitable terrain and lack of infrastructure (including lines of communication) in Afghanistan – and many other prospective Areas of Operation (AO) – make movement to and maneuver within the AO extremely difficult to plan and execute. Without a ready source of logistics, it is essential that operations be self-sufficient and self-sustaining to the maximum extent possible. These requirements, unfortunately, run precisely counter to the long-recognized need to reduce the sheer burden borne by the infantry and Special Operations Forces (SOF), as articulated in military writings such as S.L.A. Marshall's 1950 copyrighted classic "The Soldier's Load and the Mobility of a Nation." Ironically, well-meaning technologists and logisticians (who will never carry the crushing burdens themselves at a dead run, at high altitude, and in temperatures well over 130 degrees Fahrenheit) regularly add to our warfighters' load with a slew of great ideas.

In the present context, what is needed is a means of increasing the mobility of dismounted Marines in order to provide them with increased speed, lethality, and survivability in an inhospitable terrain. A promising avenue of inquiry is an investigation resulting in a market survey involving the rapidly-developing field of unmanned ground systems.

To this end, the Office of Naval Research Expeditionary Maneuver Warfare and Combating Terrorism Department (ONR-30) commissioned the Unmanned Systems Branch (7171) of the Space and Naval Warfare Systems Center Pacific to conduct this detailed survey and analysis of current and developing robotic technologies to support the dismounted Marine. The following sections will detail the survey and analytical process by which the results were obtained.

OFFICE OF NAVAL RESEARCH

The Expeditionary Maneuver Warfare and Combating Terrorism Department (Code 30) of the Office of Naval Research is the sponsor for this effort. ONR's role is to advance the scientific knowledge necessary to support naval technology with a future-focused vision for the United States Navy and Marine Corps. ONR-30's role is the development and transition of technology that will enable Navy and Marine Corps forces to fight, survive, and win on the battlefield of the future through the exploitation and application of science and technology.

The main objective of this study is to conduct a technology market survey of unmanned ground vehicles and related technologies coupled with an expert analysis in support of the Small Unit Mobility Enhancement Technologies strategy at ONR. The specific focus is on tactical unmanned ground systems capable of supporting an increase in the mobility of dismounted Marines operating in

a tactical environment, lightening the load of the individual Marine, and possibly providing a logistical re-supply capability for small units.

BACKGROUND

As Marines and soldiers engaged in Operations Enduring and Iraqi Freedom (OEF / OIF) will tell you, 21st Century or not, modern warfare still involves a tremendous amount of old-fashioned foot slogging. This is particularly true in areas of operation such as Afghanistan, where the infrastructure is primitive and modern amenities are few and far between.

As a result, the "maneuver" in maneuver warfare is frequently on foot and there is precious little "blitz" in blitzkrieg. The requirement to pack the necessary ammunition, supplies, PPE (personal protective equipment), food, and water for extended operations further weighs down (and slows) the tactical unit. These facts would seem to place the commander at odds with several of Clausewitz's classic principles of warfare (especially maneuver, surprise, and security). Sun Tzu similarly noted, "*Speed is the essence of war. Take advantage of the enemy's unpreparedness; travel by unexpected routes and strike him where he has taken no precautions.*"

One obvious and pragmatic approach to the mobility problem involves the use of pack animals, but there are a number of drawbacks. For instance, the animals must be acquired locally (due to issues of animal health and resistance to local diseases). Furthermore, pack animals are not well suited to most forms of maneuver warfare – for instance, they tend not to thrive while riding in helicopters, airplanes, or amtracs – thereby limiting their usefulness in anything other than close-in and localized operations.

Consequently, in the latter part of May 2009, SSC Pacific was approached by the Office of Naval Research to perform a market survey and analysis of off-the shelf and near-term (one year) development UGVs able to carry a minimum of 70 pounds of payload, as well as a UGV able to carry up to two Marines. The objective is to carry the loads for dismounted Marines without losing the inherent flexibility of dismounts. A series of requirements was articulated and subsequently refined describing the capabilities and functionality desired of the target UGV.

With only 3 months available for project performance, this report represents an aggressive and fast-paced data collection and analysis effort. SSC Pacific dedicated the efforts of a dozen individuals (including full-time SSC Pacific employees, supporting Naval Reservists, and student interns) to this effort. While a longer performance period would have permitted greater interaction with the manufacturers and system operators, sufficient information to develop a baseline analysis of current systems measured against the ONR performance criteria was obtained.

PERFORMANCE REQUIREMENTS

A central aspect of this tasking was to identify and rank commercial off-the-shelf (COTS) systems for their relevance in supporting the dismounted Marine. As research progressed, this came to include the evaluation of over 500 systems, located internationally. The performance characteristics of interest identified by ONR for initial assessment are listed in Table 1. The characteristics included both "minimum" and "desired" performance attributes. These elements provided the basis for the scoring and ranking criteria in the report.

Table 1. System Performance Requirements for Dismounted Marine Support

Performance Attribute of interest	Minimum Performance	Desired Performance
Mission Length (duration of unassisted operation)	2 days	5 days
Mission Range (range in miles without refueling/changing batteries.	5 miles	30 miles
Autonomy (self-directed movement)	Ability to follow the leader in line of sight with Marine rifle team	Ability to follow, meet, etc. dismounted Marines without increasing the mental or physical workload of the Marines
Communications Capabilities	Wireless communication interfaced with wearable computer or similar device for Marine dismount data entry	UGV response to a range of Marine communications, including words, whistle, hand-and-arm signals, beacons, etc.
Mobility	Able to cover urban and non-mountainous desert vehicle roads including debris greater than 12 inches height, ditches greater than 3 feet in width at dismounted Marine running speed, (update with NATC)	Able to cover >= 95% of the terrain that a Marine is able to cover, while wearing individual equipment (including fording rivers, climbing through windows, navigating in caves, climbing over urban rubble and boulder fields, etc.) at running speed
Pay Load	50 lbs	1,200 lbs
Transportability	V-22 Osprey compatible	Fire team and UGV may be simultaneously transported (internally) with a V-22 Osprey
Recoverability	1. Can be recovered with a winch; and/or 2. Can be recovered by four 50-percentile Marines	1. Can be recovered with a winch; and/or 2. Can be recovered by two 50-percentile Marines

Each of these attributes and the associated scoring mechanism are explained in the analysis. It must be noted that the goal of this study was the analysis of platforms that supported the environment and the tasks associated with the dismounted Marine. Consequently, many in-theater UGV systems designed for specialized tasking did not meet evaluation criteria, including explosive ordnance disposal (EOD) support robots and mine-clearing platforms, two important UGV missions.

In evaluating UGV system capabilities in support of the dismounted Marine, it is important to consider some of the underlying tasks that a robotic platform might perform within a mission profile. A 2004 North Atlantic Treaty Organization (NATO) workshop included a working session of military members who sought to identify potential tasks and the associated gaps in actual field deployment; the resulting document was titled “Bridging the Gap in Military Robotics” (NATO/TRO

2008). Table 2 lists the tasks identified by this group. Many of the tasks listed in this table are similar to the requirements currently facing Marines and other warfighters in theater.

Table 2. Potential Military Tasks for Robotics Support

To a great extent • Carry equipment for dismounted warfighter • Checking vehicles and people for explosives and weapons at checkpoints • Convoying – transport of goods • De-mining – clearing fields from AP[1] and AT mines • De-mining – tactical • Detect NBC • Detecting and marking mines – both AT and AP[2] • Reconnaissance in urban warfare • Surveillance and security – military camps and areas – compounds • De-mining – tactical and post-conflict – clearing roads and fields from AP and AT mines • Reconnaissance and surveillance for tactical support for the forces on the ground, including NBC[3]
To some extent • Countermeasures against robots • Decontaminate from NBC • Decoys and diversion • Detection of snipers • EOD – making explosive devices harmless • Information infrastructure • Medevac • Recovering damaged vehicles and other materials • Refueling and ammunition supply as Combat Service Support • Self-defense system for non-armored vehicles and convoys • Self-mobile surveillance (e.g., flank protection) • Shooter for all calibers • Surveillance – wide area in open ground and long endurance • Surveillance – wide area in urban area and long endurance • Throwable robot for infantry • Underground vehicle for various tasks (listening, place mine, remove mine)
To a small extent • Breaching bushes – (tank) ditches • Clearing beach obstacles • Clearing snow and dirt from airfield runways • Information operations in urban terrain • Intelligent – moving minefield

The ultimate goal of this project and the supporting ONR office is to support the mobility and mission tasking of the dismounted warfighter. This is not a new concept; Everett et al. (2004) discussed the concept and challenges facing a futuristic “Warfighter’s Associate,” a system intended for proximal human–robot teaming and equipped to complement human capabilities with its specific robotic strengths. A familiar analogy is the pairing of police officers with canine partners in both

[1] AT — Anti-tank

[2] AP — Anti-personnel

[3] NBC — Nuclear, Biological, and Chemical

military and civilian law-enforcement applications. In this scenario, the officer's abilities are supplemented by those of the canine partner, which possesses, among other attributes, perception and mobility skills far superior to that of the human.

An analogy applicable to dismounted support is that of a mule – which is not necessarily chosen for its sensory capabilities, but rather for its sheer strength, reducing the burden on the Marine. The "mule" concept has actually been the inspiration for military UGV development programs, including the Defense Advanced Research Projects Agency's (DARPA) Legged Squad Support System (LS3) Program.

DARPA's LS3 Program is an effort to develop a walking platform, preferably a quadruped, which can accompany dismounted Marines and soldiers and increase their combat capability and effectiveness (Table 3). LS3 is envisioned to augment small infantry units by maneuvering with them in complex terrain where tactical vehicles cannot go, carry traditional infantry equipment (in an effort to improve unit performance), carry new infantry equipment (in an effort to give new combat and sustainment capabilities to the unit), and do so in a self-controlled fashion (requiring minimal human interaction and control). For additional information, refer to DARPA BAA 08-71, http://www.darpa.mil/tto/solicit/index.htm.

Table 3. Performance Goals in DARPA's LS3 Program

		
	LS3 Goal	**Mule Characteristics**
Payload	400 lb	150 lb
Total Weight	1250 lb	1000 lb
Range	20 miles	18 miles
Endurance	24 hours	8 hours non-stop walking
Speed	3-mph walk, 5-mph trot, 10-mph burst run	2.5 mph, 5-mph trot for very short periods
Autonomy	Follow leader at 100m Short-range landmarks, GPS	After 5-6 months, can walk the distance between camps unescorted
Terrain	25° incline, 25° sideslope 12" steps, Rugged	25° incline, 25° sideslope 12" steps, Rugged
Acoustics	70 dB, 40 dB quiet mode	30 dB
Other	Self-righting; one system stowed in HMMWV[4]/JLTV[5] rear bed w/gear	Primarily human-led

[4] HMMWV — High Mobility Multipurpose Wheeled Vehicle

[5] JLTV — Joint Light Tactical Vehicle

While robotic platforms have an important and growing role in theater, serving in such functions as reconnaissance and EOD operations, the roots of the U.S. military UGVs extend back to World War I in terms of technology and concept development. This nascent UGV technology was soon adapted and deployed by other military powers. In fact, during World War II, UGV platforms emerged from France and later Germany, which deployed over 8000 units for explosive-delivery and mine-clearing operations (Everett, unpublished).

The significance, utilization, and overall importance of UGVs continue to increase and they can now be found throughout the world. The data collected for this survey represent information collected for over 500 systems from robotic vendors around the world. Figure 1 depicts the distribution of the platforms reviewed by country of origin.

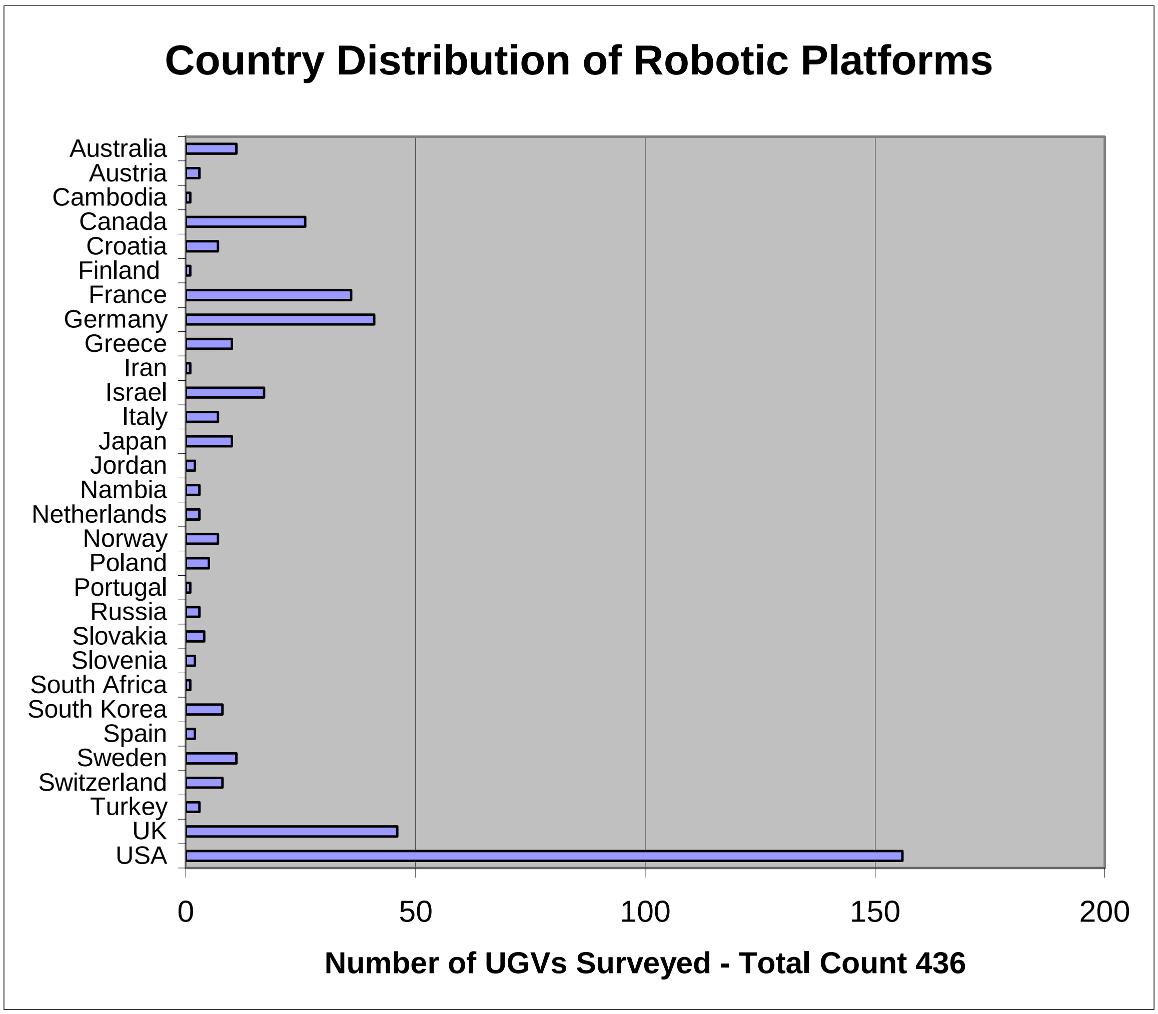


Figure 1. International Distribution of UGVs Reviewed In Market Study

SECTION II. UGV SYSTEM DATA COLLECTION

DATA COLLECTION METHODOLOGY

The scope of this project was to conduct "an encyclopedic survey that will span the range of UGVs from the iRobot Packbot size up to the size of a Humvee." With this as a starting point, more than 500 systems (later reduced to 436 through elimination of duplicates, etc.) were identified for evaluation against the ONR-specified criteria. This information was further supplemented with additional physical and performance characteristics of the UGV's when available.

Broad performance data were collected in seven categories for each of these systems, to include the following:

(1) **Organizational Information** (system name, manufacturer, website, and points of contract)

(2) **System Physical Data** (system footprint, payload, power requirements, costs, and operating restrictions)

(3) **System Autonomy Capabilities** (degree and nature of system autonomy, specifically as it pertains to support of dismounted Marine infantry units)

(4) **System Mobility** (system range, speed, operating duration, terrain limitations, and recoverability)

(5) **System Sensors / Modularity** (baseline and optional sensor configuration and modularity)

(6) **Command and Control** (communications capabilities, software architecture, and system transportability)

(7) **Operational Readiness** (Technical Readiness Level and field deployment experience)

Appendix B presents the Unmanned Ground Vehicle Market Survey elements of information that were sought from both publicly available sources and direct vendor input.

Appendix C provides a snapshot overview of each UGV system that was considered in the course of this research.

When possible, information was obtained directly from the vendor/manufacturer. For many of the systems, however, information was acquired through open-source aggregation and fusion. Open-source resources of note included:

- *Jane's Online* and, in particular, "*Jane's Unmanned Ground Vehicles and Systems*," which provided information on 212 platforms
- The International Unmanned Vehicle Systems Information Source (www.uvs-info.com)
- National Institute of Standards and Technology's (NIST) Pocket Guide to "*Response Robots: DHS/NIST Sponsored Evaluation Exercises*" (http://www.isd.mel.nist.gov/US&R_Robot_Standards/robotguide2007.pdf)

A complete reference listing is included in Section VI.

Concurrent with open-source data research, both targeted queries and broad-spectrum requests for information (RFIs) were conducted to solicit manufacture and program-sponsor input in the survey. In terms of targeted queries, we sent market surveys to selected organizations requesting information for over 200 of the most promising systems; in response, we received approximately 65 completed market survey forms, for a response rate of approximately 32%.

The market survey response rate for this survey was actually somewhat better than the experience of the North Atlantic Treaty Organization Research and Technology Organization (RTO), with respect to a questionnaire that organization promulgated regarding multi-robot systems. The RTO survey was sent to 255 research facilities, companies, universities, and other institutions concerned with multi-robot systems. With significantly more time and resources available to them, these researchers found that, after the initial questionnaire and three follow-up reminders, they received a total of 60 responses, or 23.5%.

There are several likely reasons for the low response rate for the data call. First, survey response is generally acknowledged to be poor and getting worse all the time; as Johnson and Owens (2003) observe: “It is now understood that response rates have been declining, both in the United States and in most of the industrialized world, for at least several decades.” People are busy and, unfortunately, frequently inundated with survey requests and data calls of all sorts. Additionally, many organizations that received our market survey very likely self-selected out, concluding that their unmanned systems simply did not meet the criteria outlined in the survey.

In addition to the targeted queries, SSC Pacific utilized a variety of venues to more widely advertise the UGV data call, to include:

- **FedBizOpps** (Solicitation #W15QKN-09-X-1219)
  https://www.fbo.gov/index?&s=opportunity&mode=form&id=c132d4f0942a950ead3aad3d495b9ad5&tab=core&tabmode=list
- **SSC Pacific Robotics Website** (http://www.spawar.navy.mil/robots/)
  A link near the top of the webpage informs the reader, “SPAWAR Systems Center Pacific is conducting a market survey of unmanned ground vehicles (UGVs) for the Office of Naval Research (ONR). The effort is focused on unmanned ground systems capable of supporting an increase in the mobility of dismounted Marines. If you are interested in responding to this market survey, please download the Request for Information form.”
- **AUVSI Announcement** (http://newsmanager.commpartners.com/auvsi/issues/2009-08-18.html#15)
  In its 18 August 2009 eBrief, the Association for Unmanned Vehicle Systems International (AUVSI) included a notice titled “SPAWAR Seeks UGV Information” with a link to the SSC Pacific robotics site (http://www.spawar.navy.mil/robots/) where visitors could download the market survey RFI form.
- **SSC Pacific Robotics Newsletter** (Spring 2009, Volume 9, No. 1) A notice at the bottom of page 1 calls readers’ attention to the research effort and invites them to visit SSC robotics webpage to download the market survey form: “*SPAWAR Systems Center Pacific is conducting a market survey of unmanned ground vehicles (UGVs) for the Office of Naval Research (ONR). The effort is focused on unmanned ground systems capable of supporting an increase in the mobility of dismounted Marines. If you are interested in responding to this market survey, please visit http://www.spawar.navy.mil/robots/ and download the form.*”

When possible, researchers at SSC Pacific made direct contact with UGV system developers/manufacturers. This mainly involved telephone and email exchange, but also included site visits by SSC Pacific personnel to the developer or UGVs operator’s facility. SSC Pacific frequently

had prior working knowledge of many of the systems reviewed and, in some cases, was in possession of the system being evaluated.

INITIAL DATA CULLING

With over 500 systems initially identified during the Data Collection phase of the project, it was clearly necessary to execute a culling of the systems in order to reduce the total number to something more workable.

Consequently, several review sessions were held, principally to identify those systems that appeared incapable of meeting one or more of the ONR-specified criteria. The criteria that we selected at this stage of the process included the following:

- **Mission Duration** (minimum of 12 hours)
  (Technology Capability #1: Mission Length)
- **Speed** (at least 6.0 kph or 3.75 mph – slow running speed)
  (Technology Capability #5: Mobility)
- **Payload** (minimum of 50 pounds)
  (Technology Capability #6: Payload)
- **Weight** (less than 20,000 pounds, in order to be V-22 Osprey compatible)
  (Technology Capability #7: Transportability)
- **Dimensions** (not greater than the interior cargo dimensions of the V-22 Osprey)
  (Technology Capability #7: Transportability)

The selected culling criteria were either the same as, or somewhat less rigorous than, the “Minimum Performance” standards stipulated by ONR in the statement of work (SOW). The V-22 Osprey characteristics were acquired by contacting the Osprey program manager.

By applying these criteria, we discovered that these preliminary culling sessions effected an initial reduction of about 2/3, from 436 to approximately 147 systems. Most of the disqualified systems were either much too large and would never be capable of being transported by the V-22 Osprey (e.g., large mine flails, tanks, etc.), or quite small and very slow, with extremely limited payload capacity (e.g., throwbots and a large contingent of very small UGVs).

Of the remaining 1/3 still in the running, a small number nominally met the criteria described above, whereas the greater number had insufficient data at this stage to accurately classify them, necessitating further investigation and due diligence.

SYSTEM RANKING

To further identify candidate systems, the scoring method depicted in Table 4 was developed to permit system ranking, with a total of 55 points possible.

Table 4. System Ranking and Scoring

Capability		Scoring Value				
	Notes	1	2	3	4	5
1. Mission						
Mission Length	Hours	12	24	48	72	96
2. System Range						
Range (Without Refueling)	Miles	1 ≤ x < 5	5 ≤ x < 10	10 ≤ x < 25	25 ≤ x < 50	50 ≤ x
3. Autonomy						
Autonomous Navigation		Pre-programmed waypoint		Waypoint plus obstacle avoidance		Able to “Follow the Leader”
4. Communications						
Communications Capabilities		Wireless comms		Redundant comms – (two or more systems)		Response to a range of comms, (words, whistle, hand-and-arm signals, etc.)
5. Mobility						
Mobility (Part I)	Max Speed	x < 5 (mph)	5 ≤ x < 10 (mph)	10 ≤ x < 25 (mph)	25 ≤ x < 50 (mph)	50 ≤ x (mph)
Mobility (Part II)	Able to Traverse	≥12” vertical obstacle	≥18” vertical obstacle	≥24” vertical obstacle	≥30” vertical obstacle	≥36” vertical obstacle
Mobility (Part III)	Able to Traverse at speed	Ditches ≥ 12” width	Ditches ≥ 24” width	Ditches ≥ 30” width	Ditches ≥ 36” width	Ditches ≥ 48” width
Mobility (Part IV)	Able to Traverse Water (Depth)	x < 6”	6” ≤ x ≤ 12”	12” < x ≤ 24”	24” < x ≤ 48”	48” < x
6. Payload						
Payload	Lbs	50≤x<70	70≤x<100	100≤x<500	500≤x<1200	1200≤x
7. Transportability						
V-22 internally transportable with system weight of:	Lbs	1000 ≤ x < 5000 lbs	500 ≤ x < 1000 lbs	200 ≤ x < 500 lbs	100 ≤ x < 200 lbs	x < 100 lbs
8. Recoverability						
Recoverability (Small Systems)	.	Recoverable by winch		Recoverable by four 50-percentile Marines (Weight < 408 lbs)		Recoverable by by two 50-percentile Marines (Weight < 164 lbs)
Recoverability (Large Systems)		Recoverable by winch		Recovery by tele-operation		Can manually get in and drive unit

The scoring was used as an objective means to quantify system fitness for minimum and desired platform goals identified by ONR (refer also to Table 1). When information was not precisely stated in collected materials and the manufacturer could not be contacted, performance assumptions were made based on standard engineering principles. Most of these cases related to mobility characteristics (i.e., traversal of vertical and horizontal obstacles).

SECTION III. SURVEY RESULTS

The UGV systems were independently scored by three SSC Pacific engineers. Following the initial tallies, scores were reviewed for cross-reviewer consistency. Where a discrepancy of three or more points existed in overall scores between any two reviewers, conferences were held and the systems were discussed in detail until consensus was achieved.

The ranking resulted in the break-out group of systems shown in Figure 2 and Table 5. It is worthy of note that no platform achieved a score greater than 35/55. Each of the platforms and subsequent performance areas will be examined in detail.

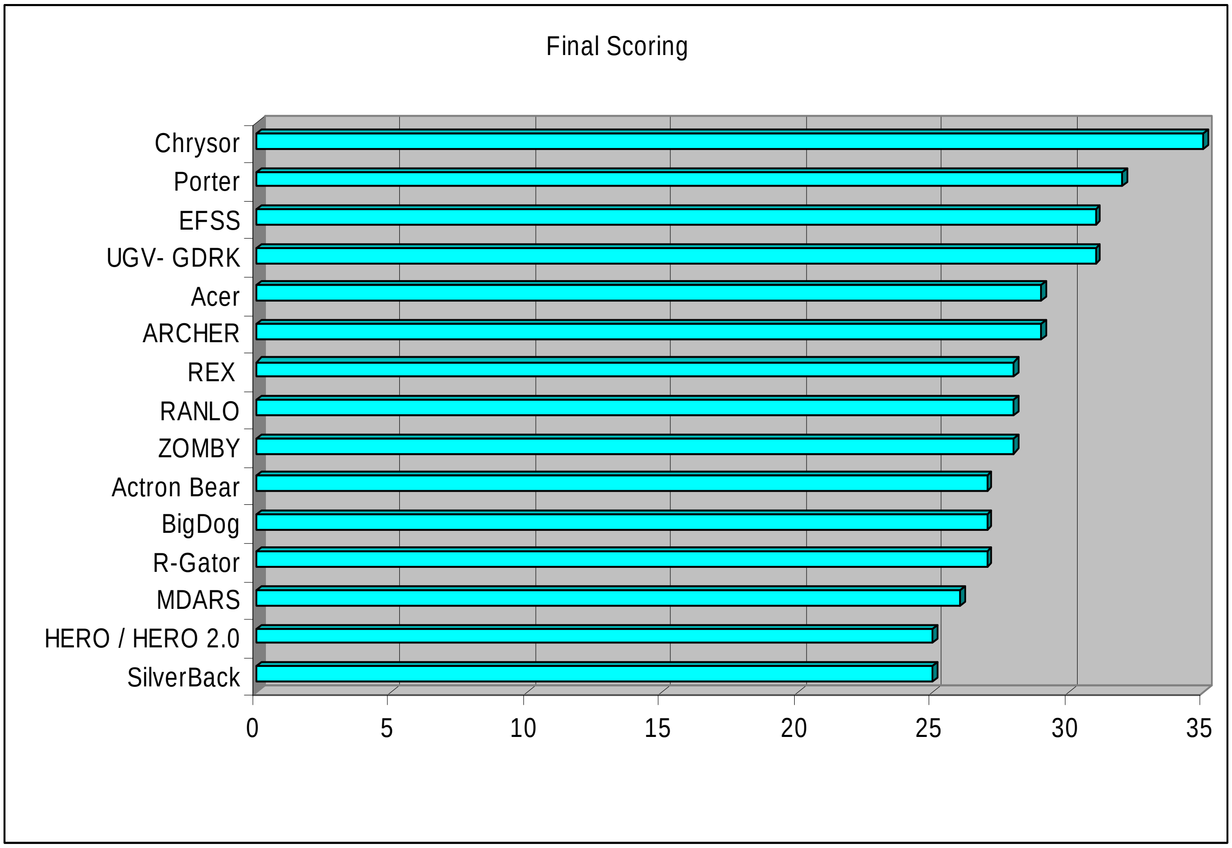


Figure 2. Top 15 Candidate System Scores

Table 5. Selected Data for Top 15 Candidate Systems

System Name	Manufacturer	System Website	Gross Vehicle Weight (lbs)	Payload Weight (lbs)	Power / Fuel Required
Chrysor	Robowatch Technologies GmbH	http://www.robowatch.de/index.php?id=303	2094	1500	Diesel
Porter	Vecna Technologies, Inc.	http://vecnarobotics.com/solutions/porter.shtml	>1000	<600	Hybrid: fuel (JP8) / electric
EFSS	American Growler, Inc	http://www.capitaldefense.com/AmericanGrowler.shtml	4536	2000	JP8
Unmanned Ground Vehicle (UGV) Safe Operations (Safe Ops) T2 using GDRK robotic control technologies.	General Dynamics Robotic Systems (GDRS)	http://www.gdrs.com	6,100	2000	Gasoline
Acer	Mesa Robotics	www.mesa-robotics.com	4500	2500	Diesel
ARCHER / Archer BATTLEWAGON	Elbit Systems of America	http://www.elbitsystems-us.com	500-1200	200-600	DIESEL or GASOLINE
REX – Infantry Robotic Porter	IAI – Israel Aerospace Industries Ltd	www.iai.co.il	400	400	Hybrid Gasoline/ Electric
RANLO	Defense Technologies	www.dtiweb.net	1000	500	Gasoline
ZOMBY	Invenscience LC	www.invenscience.com	640	700	Gasoline
Actron Bear	Acrotek, Inc	www.acrotek.com	2500	2500	Diesel
BigDog	Boston Dynamics	http://www.BostonDynamics.com/robot_bigdog.html	240	120-300	Hybrid: Gasoline/ Batteries
R-Gator Large wheeled logistics and patrol UGV.	iRobot.	http://www.irobot.com/sp.cfm?pageid=141	1450	1400	
Mobile Detection Assessment Response System (MDARS)	General Dynamics Robotic Systems	http://www.gdrs.com/about/profile/pdfs/0206MDARSBrochure.pdf	3500	500	Diesel
HERO / HERO 2.0	Radiance Technologies, Inc	http://www.auburn.edu/research/vpr/sri/nationalsecurity.htm	1300	200	Diesel / JP-8
SilverBack	Codarra Advanced Systems Pty Ltd	http://www.codarra.com.au/products/silverback.jsp	500	220	Gasoline

INDIVIDUAL SCORING PERFORMANCE

Figures reflecting the analyses and scoring for each of the top 15 systems are presented in Figures 3 through 17, from highest to lowest score, depicting how well each individual system performed in each of the eight major "Technology Capability" scoring categories.

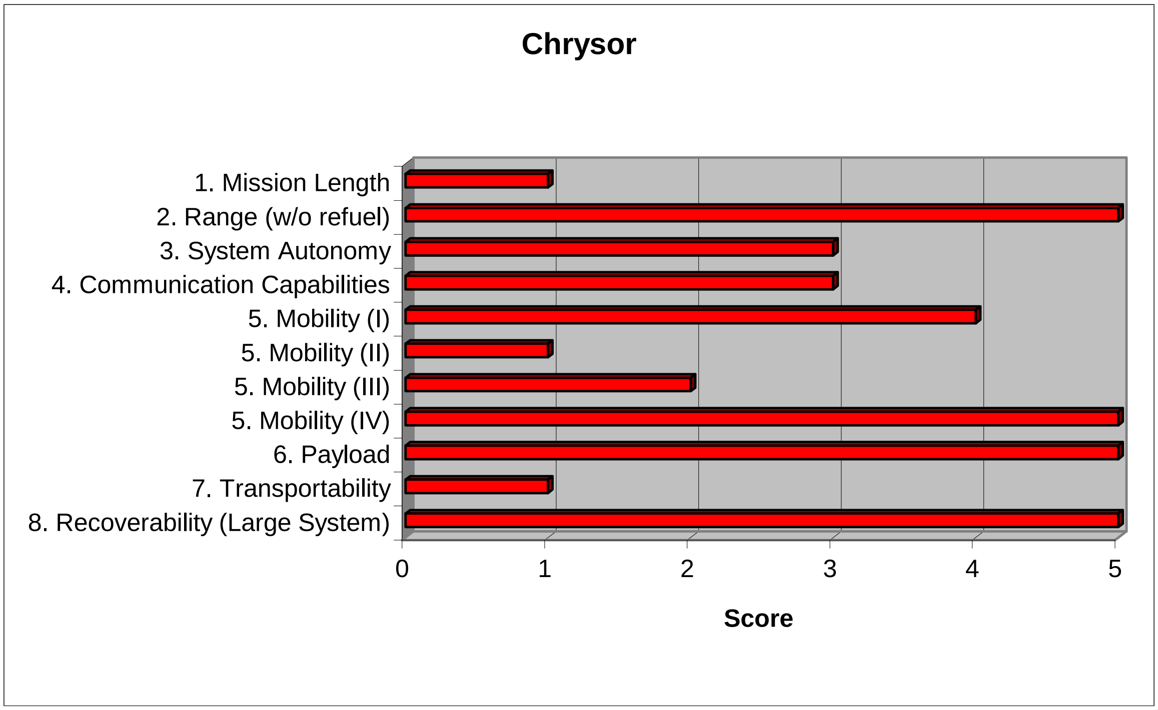


Figure 3. Chrysor (Robowatch Technologies, GmbH [6])

[6] GmbH = *Gesellschaft mit beschränkter Haftung*. GmbH is a type of legal entity very common in Germany, where it was created in 1892, and is literally translated to "company with limited liability."

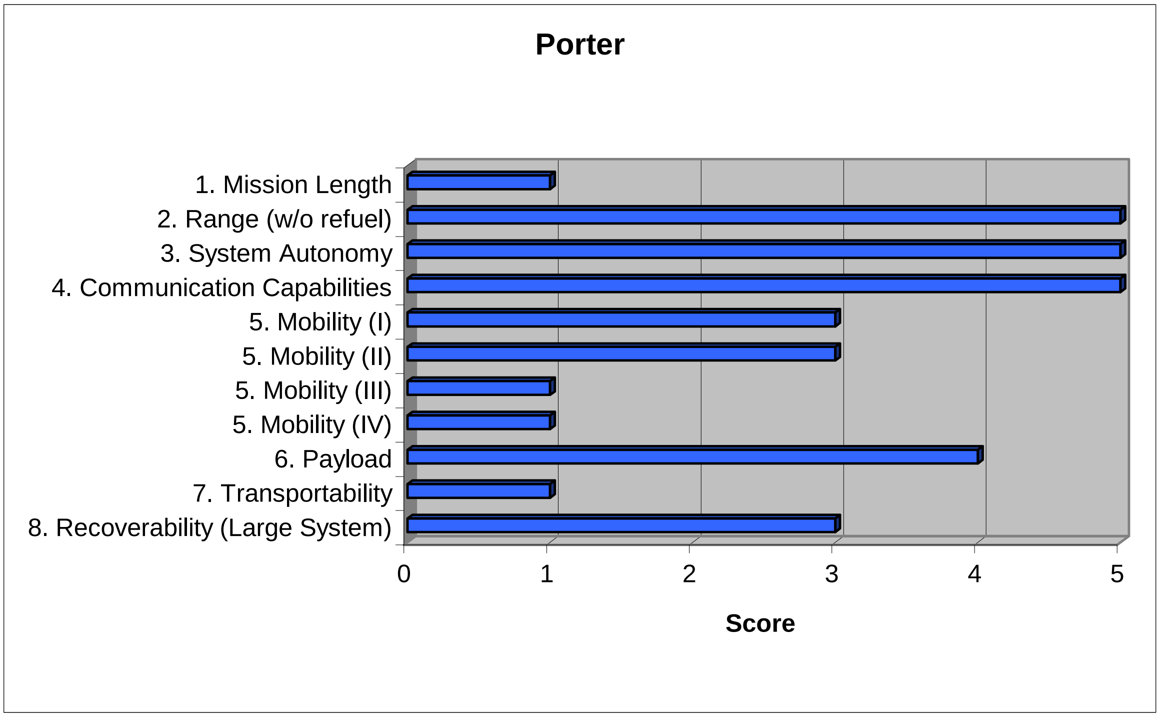


Figure 4. Porter (Vecna Technologies, Inc.)

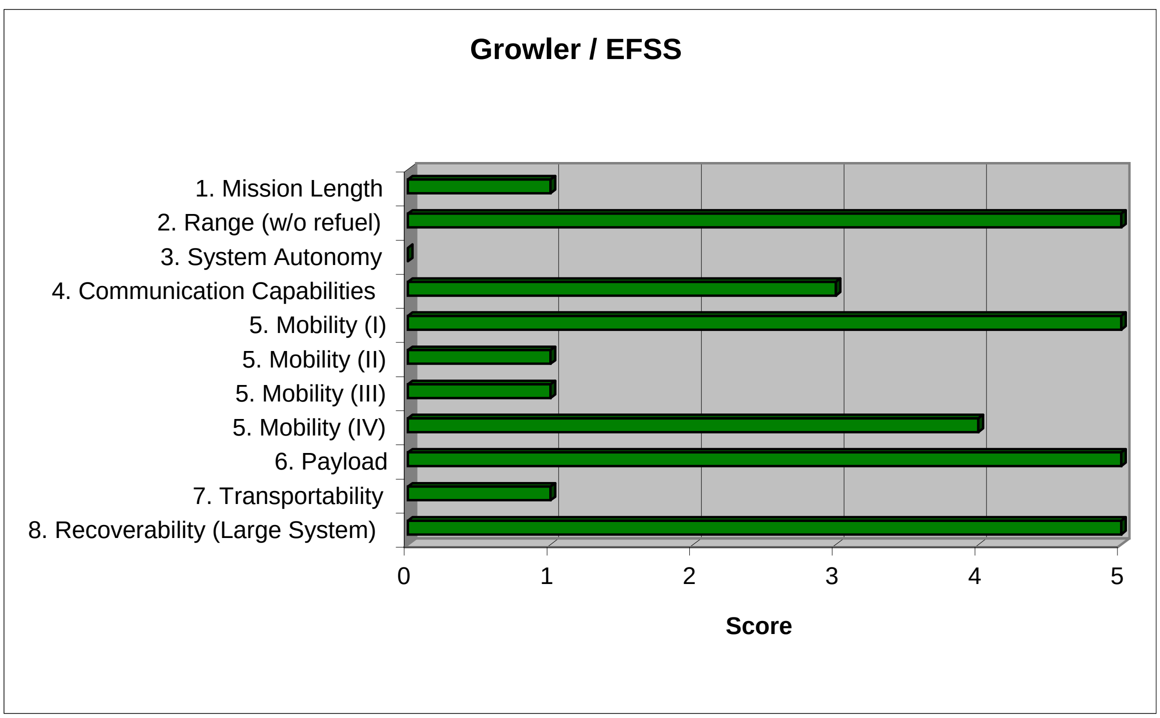


Figure 5. Growler / Expeditionary Fire Support System (American Growler, Inc.)

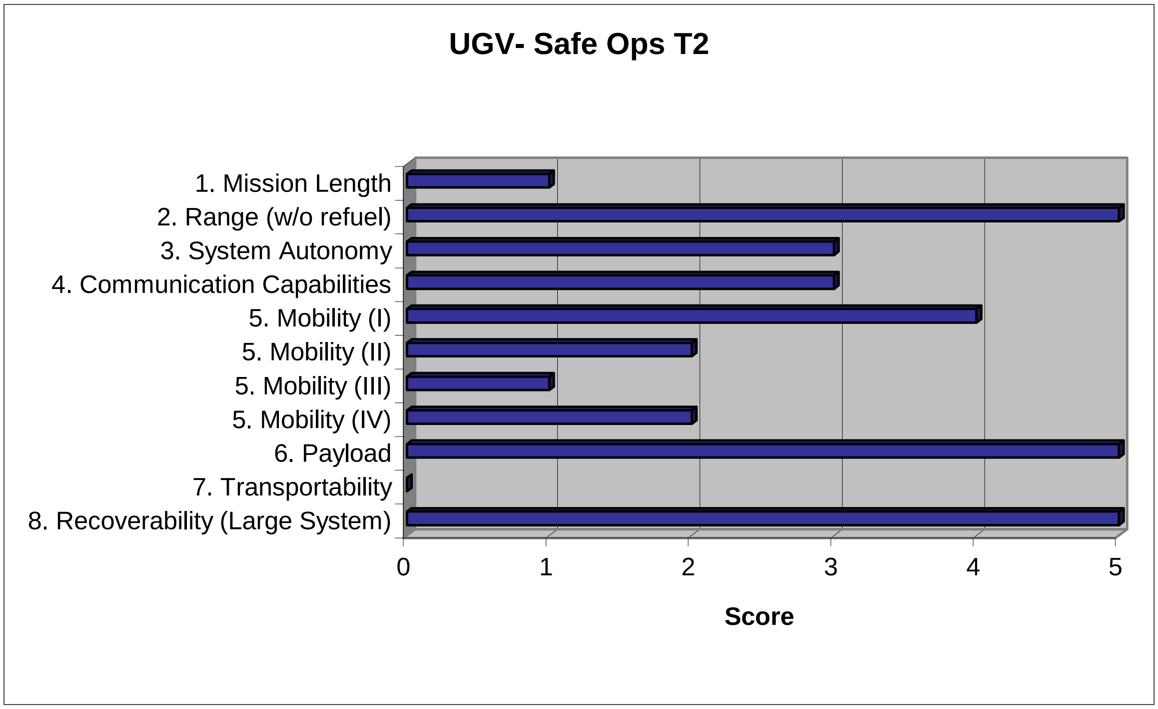


Figure 6. Unmanned Ground Vehicle Safe Operations T2 (General Dynamics)

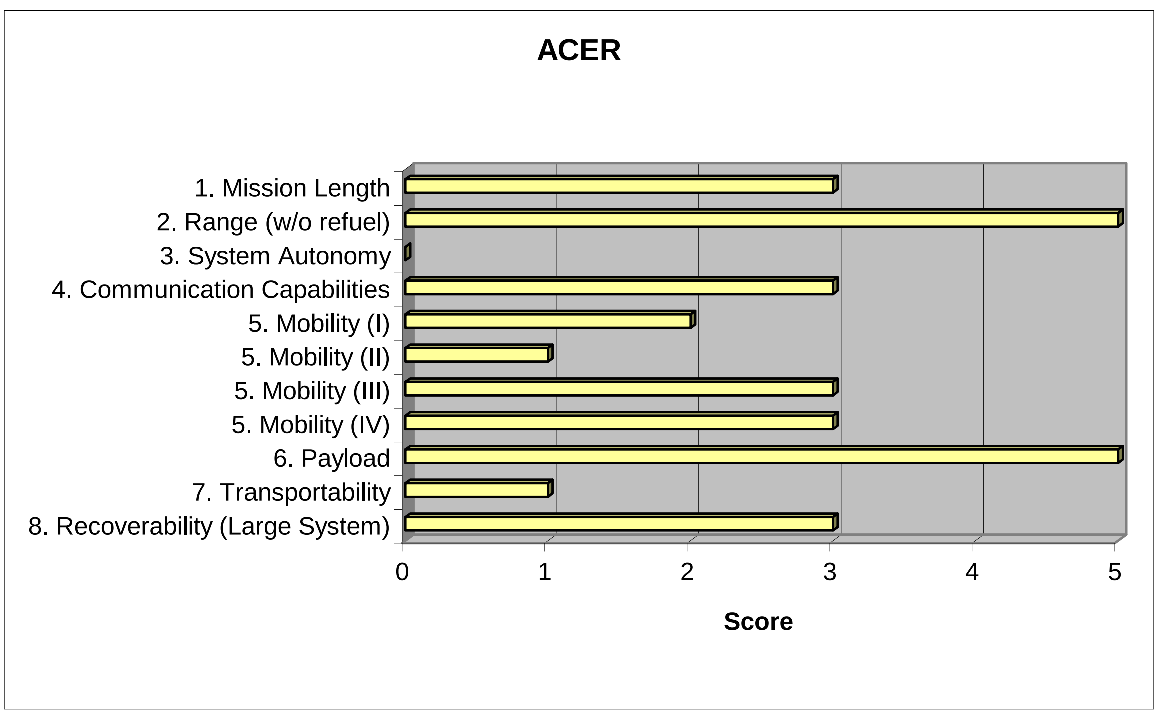


Figure 7. Acer (Mesa Robotics)

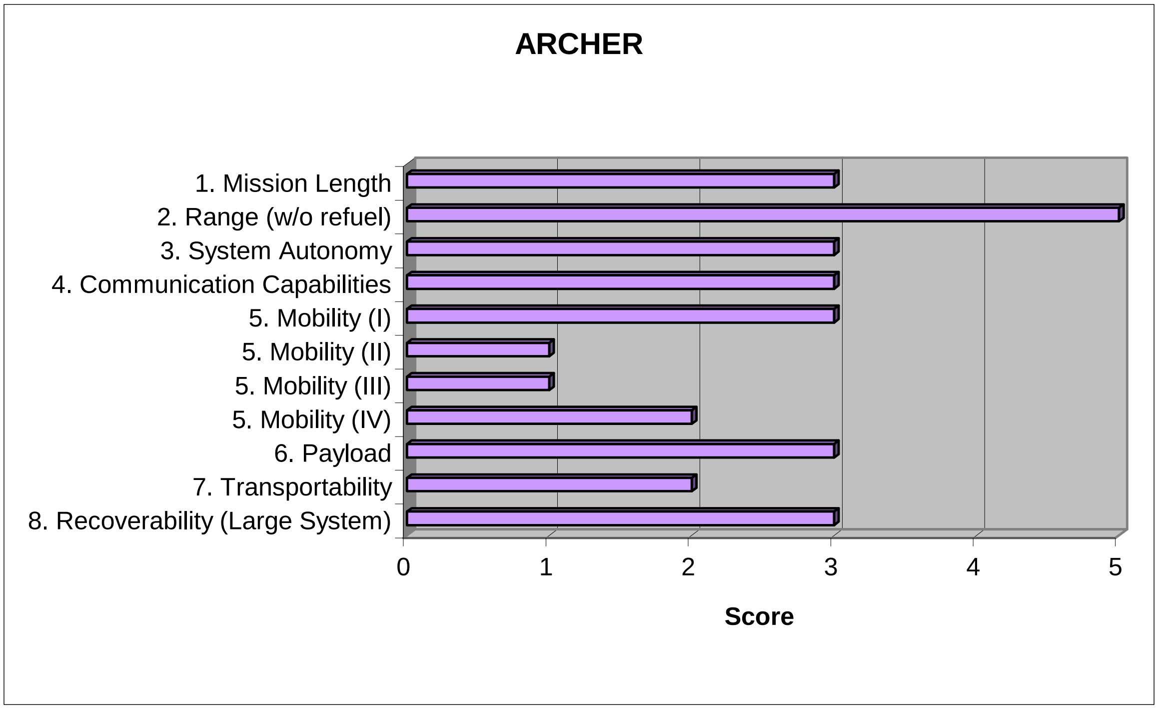


Figure 8. Archer (Elbit Systems of America)

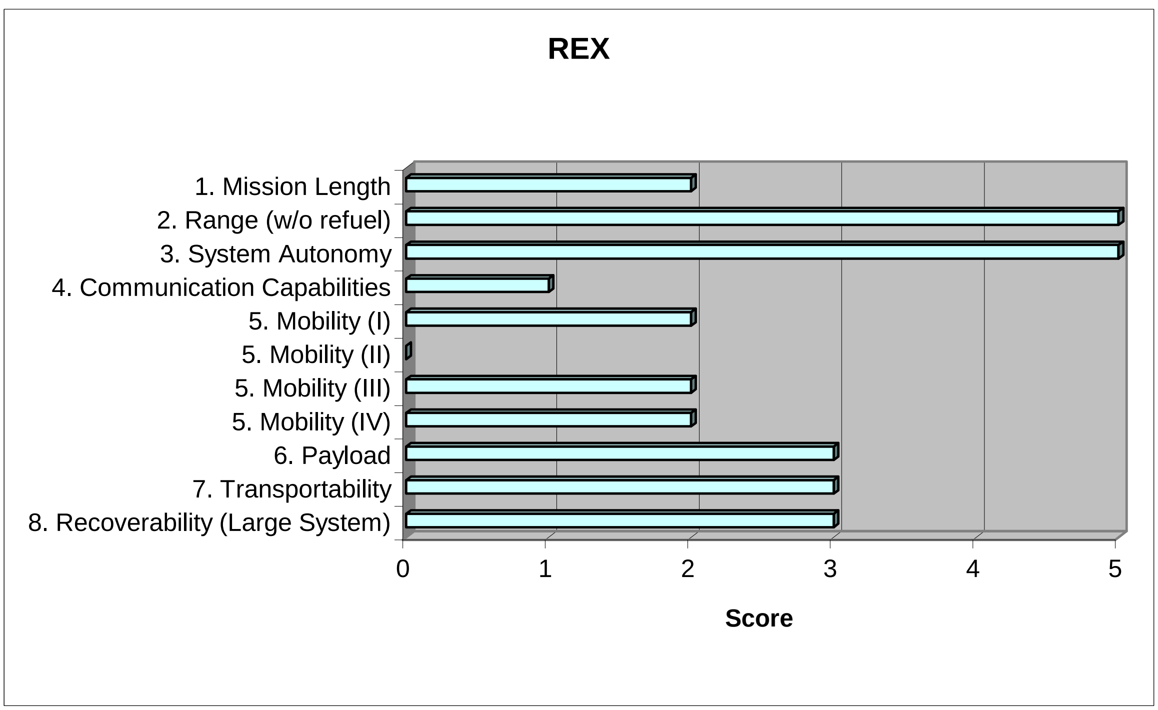


Figure 9. Rex Field Robotic Porter (Israel Aerospace Industries, Ltd.)

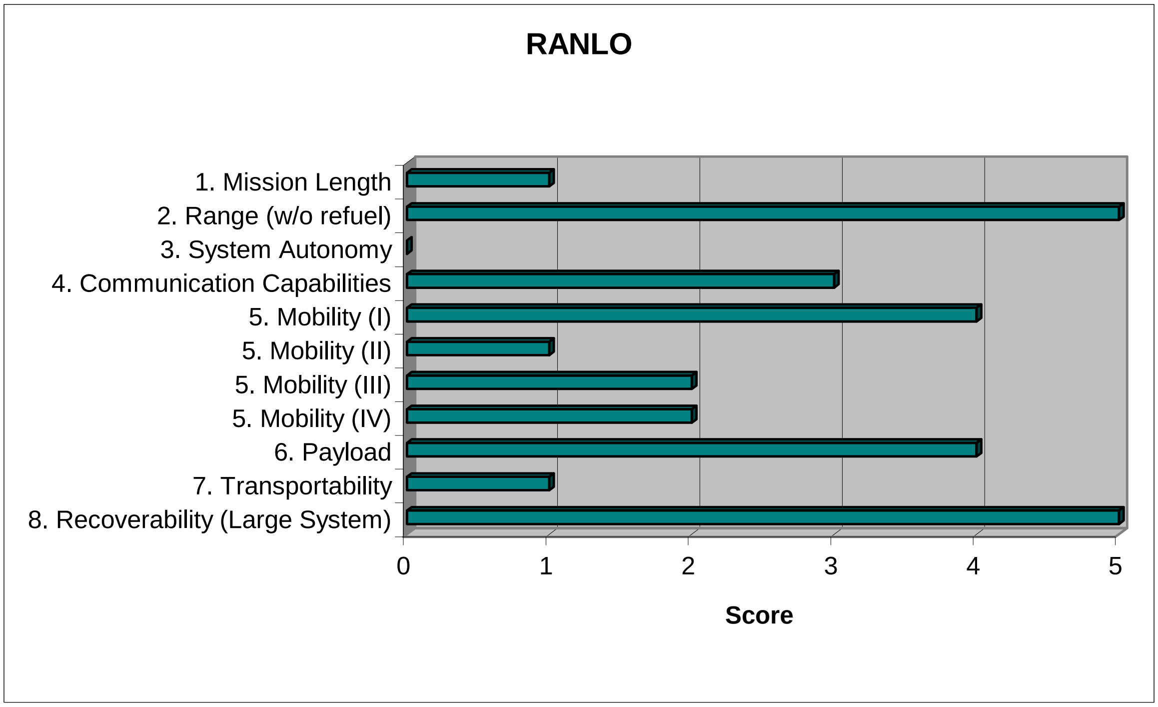


Figure 10. Ranlo (Defense Technologies, Inc.)

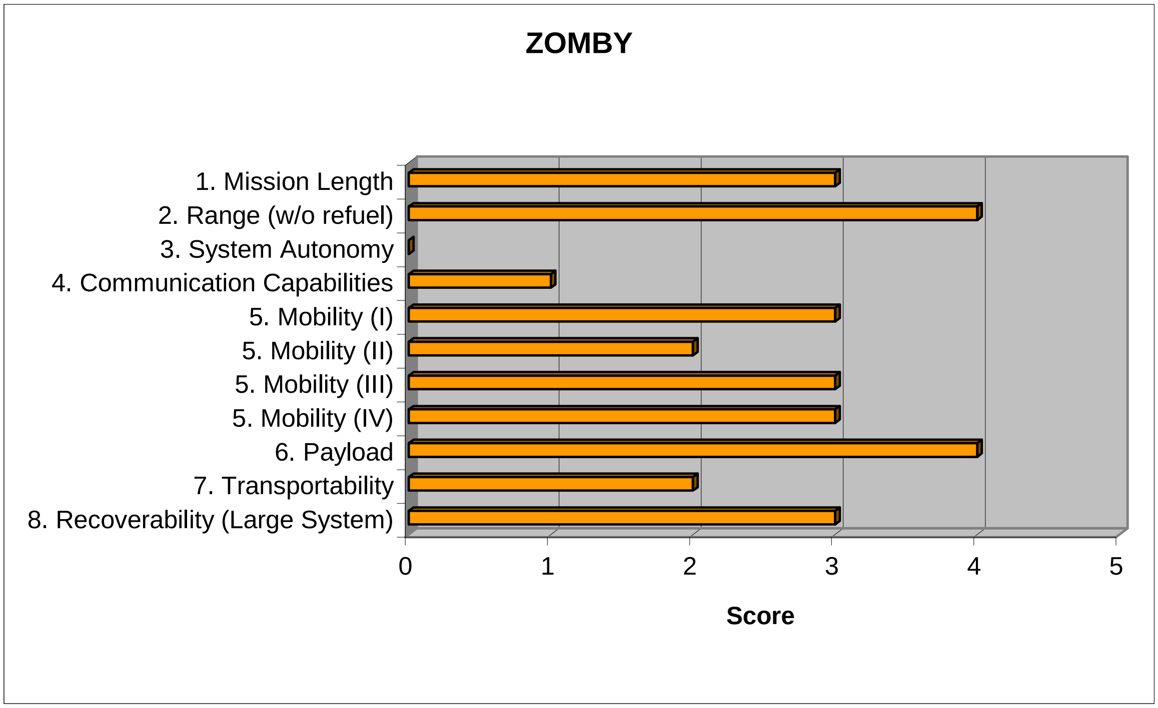


Figure 11. Zomby (Invenscience, LC)

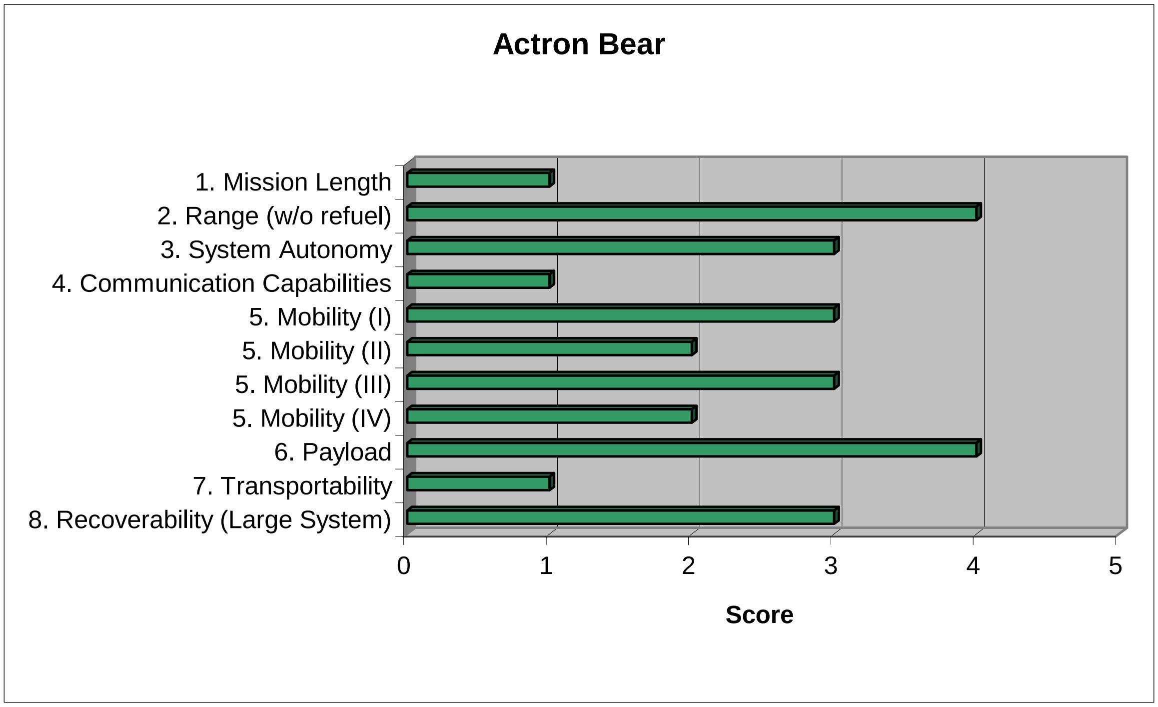


Figure 12. Actron Bear (AcroTek, Inc.)

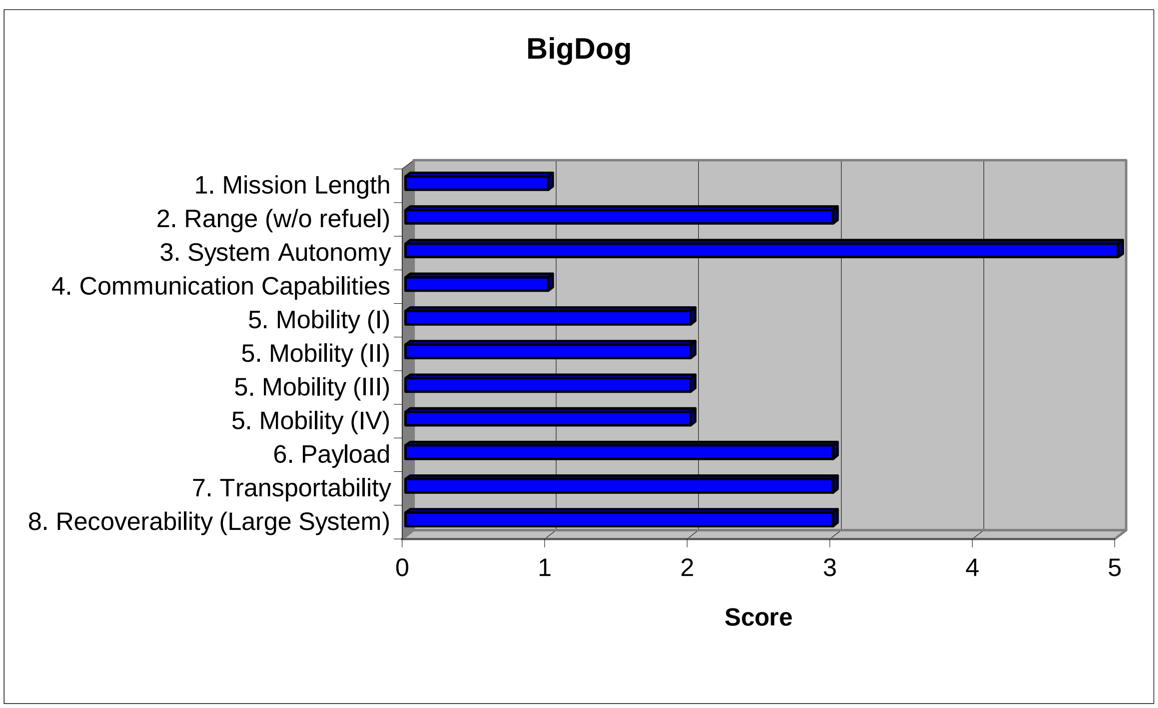


Figure 13. BigDog (Boston Dynamics)

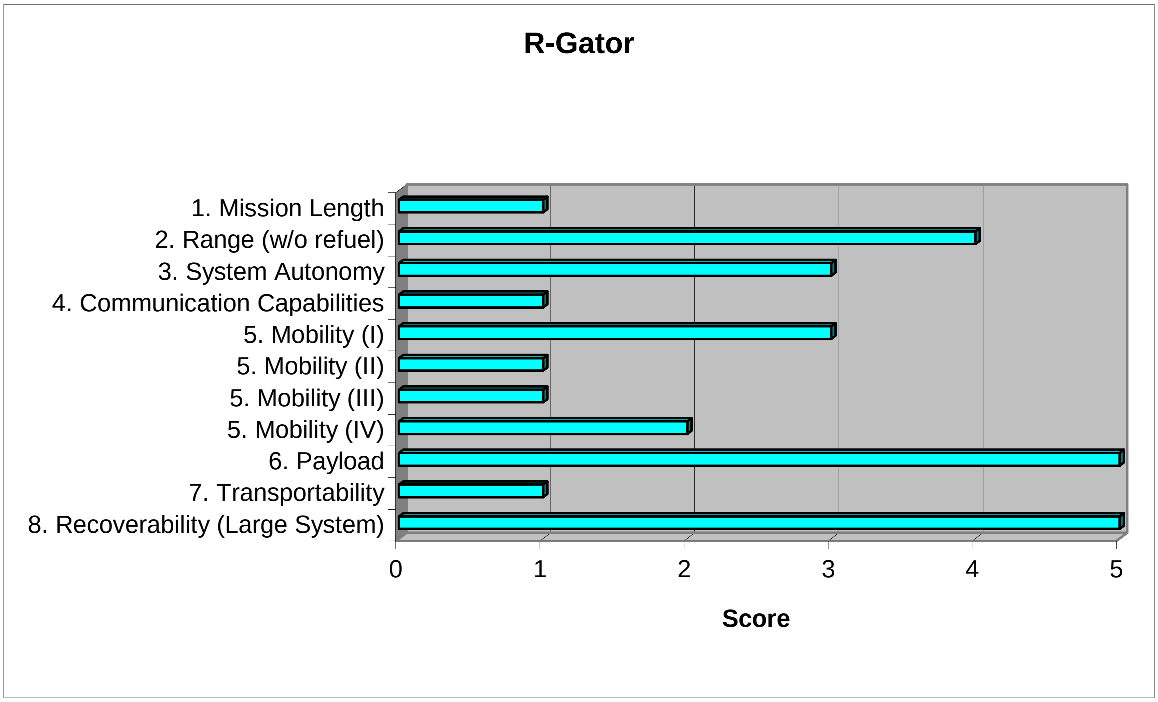


Figure 14. Robotic Gator (R-Gator) (iRobot / John Deere)

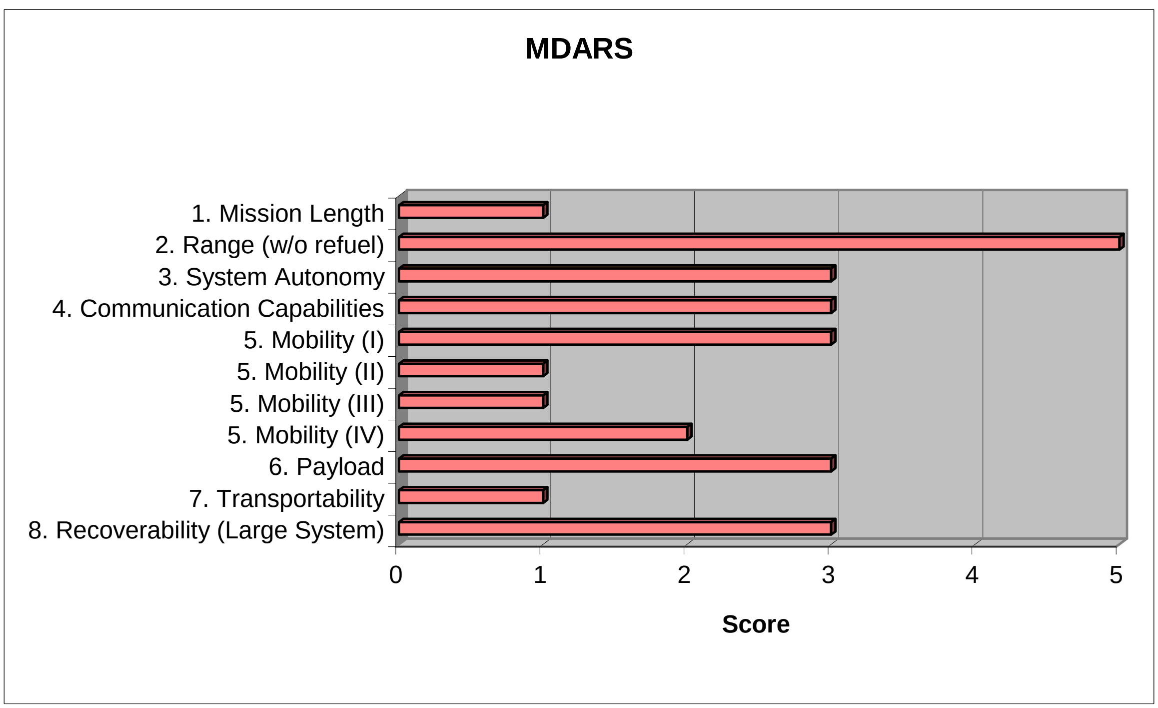


Figure 15. Mobile Detection Assessment Response System (MDARS) (General Dynamics)

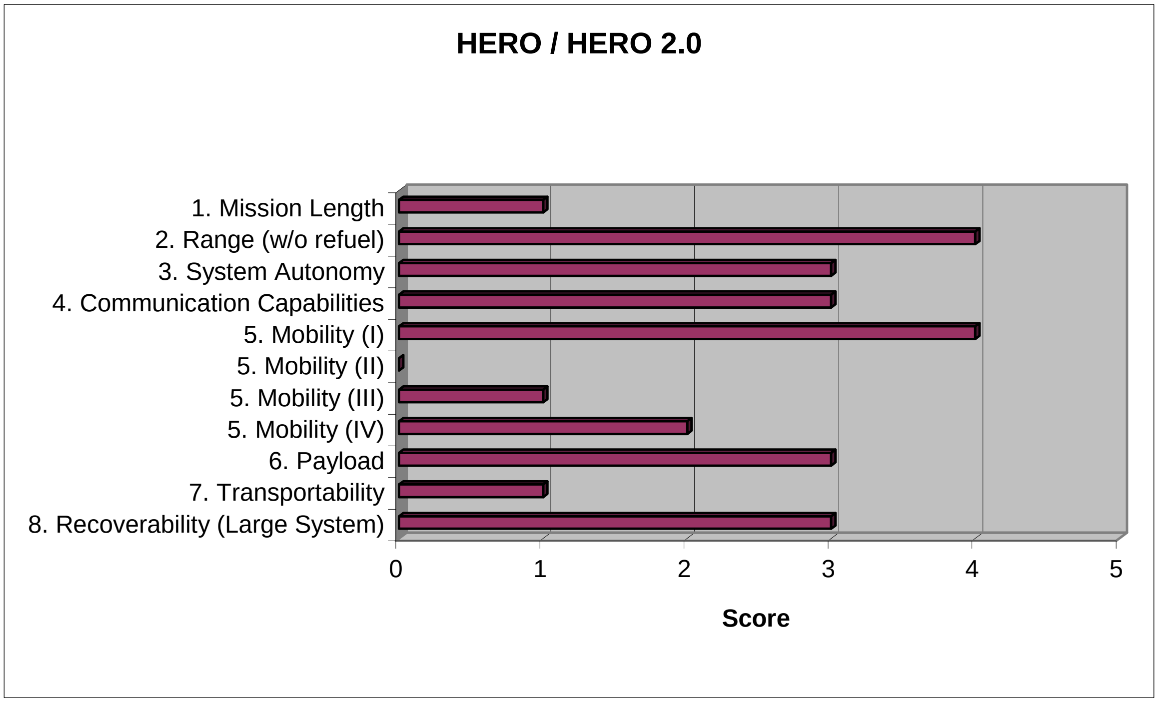


Figure 16. Hero / Hero 2.0 (Radiance Technologies, Inc.)

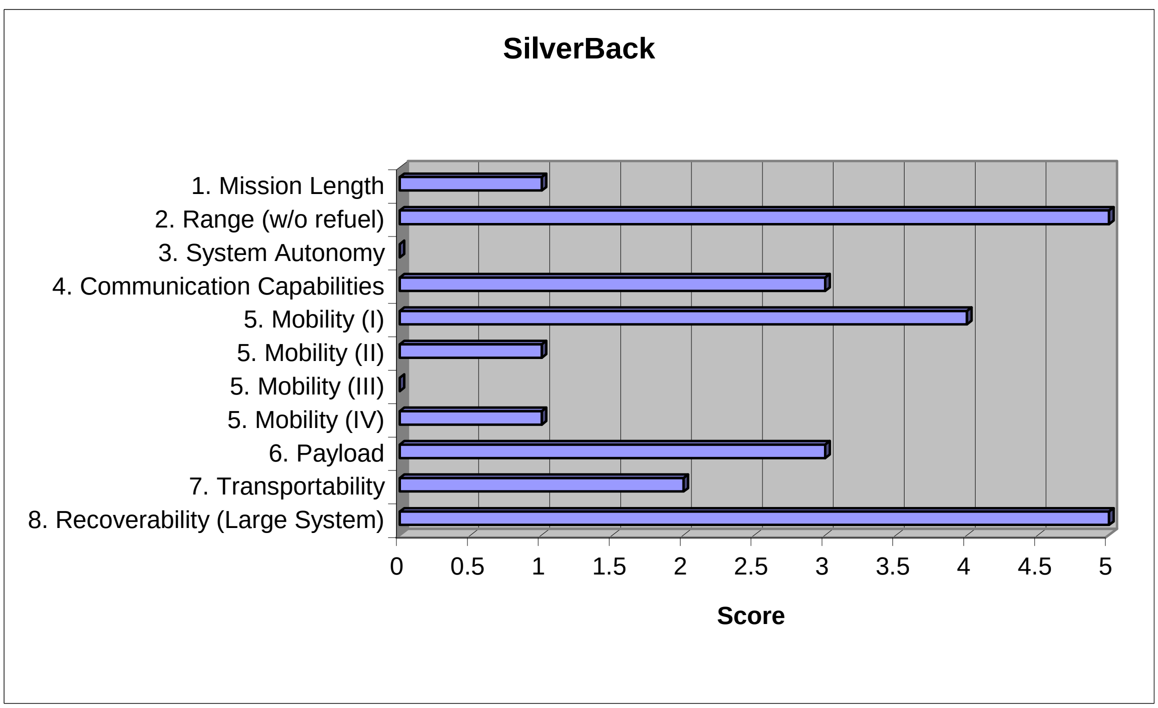


Figure 17. SilverBack (Codarra Advanced Systems Pty Ltd [7])

[7] Pty Ltd = proprietary limited, i.e., a proprietary company, as governed by Australian law.

PERFORMANCE ANALYSIS

Mission Length and System Range

One of the key challenges in the deployment of all vehicles – manned and unmanned – is that of power and the associated logistics requirements needed to maintain operational capability in the field. In addition to the power required for locomotion, additional power is needed to operate the onboard sensing and computational components. Table 6 presents the scoring approach for Mission Length, and Figure 18 depicts the system scores for this variable.

Table 6. Mission Length Scoring

Scoring		1	2	3	4	5
Mission Length	Hours	12	24	48	72	96

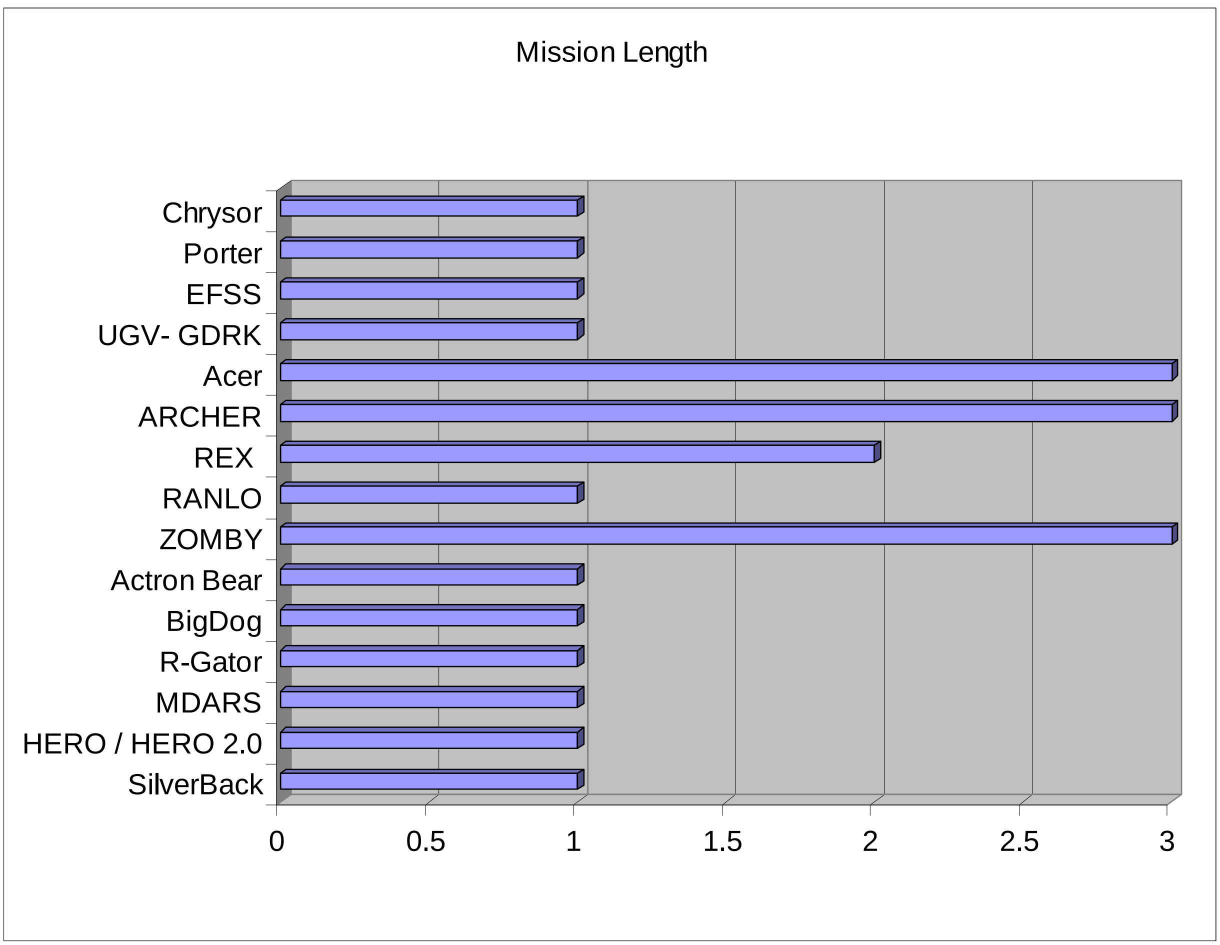


Figure 18. System Mission Length Scores

Also key to mission performance is a system's range – i.e., the overall distance that it can travel during a given mission without the requirement to stop and refuel. Table 7 presents the scoring approach for Range, and Figure 19 depicts the system scores for this variable.

Table 7. Vehicle Range Scoring

Scoring		**1**	**2**	**3**	**4**	**5**
Range (Without Refueling)	Miles	1 ≤ x < 5	5 ≤ x < 10	10 ≤ x < 25	25 ≤ x < 50	50 ≤ x

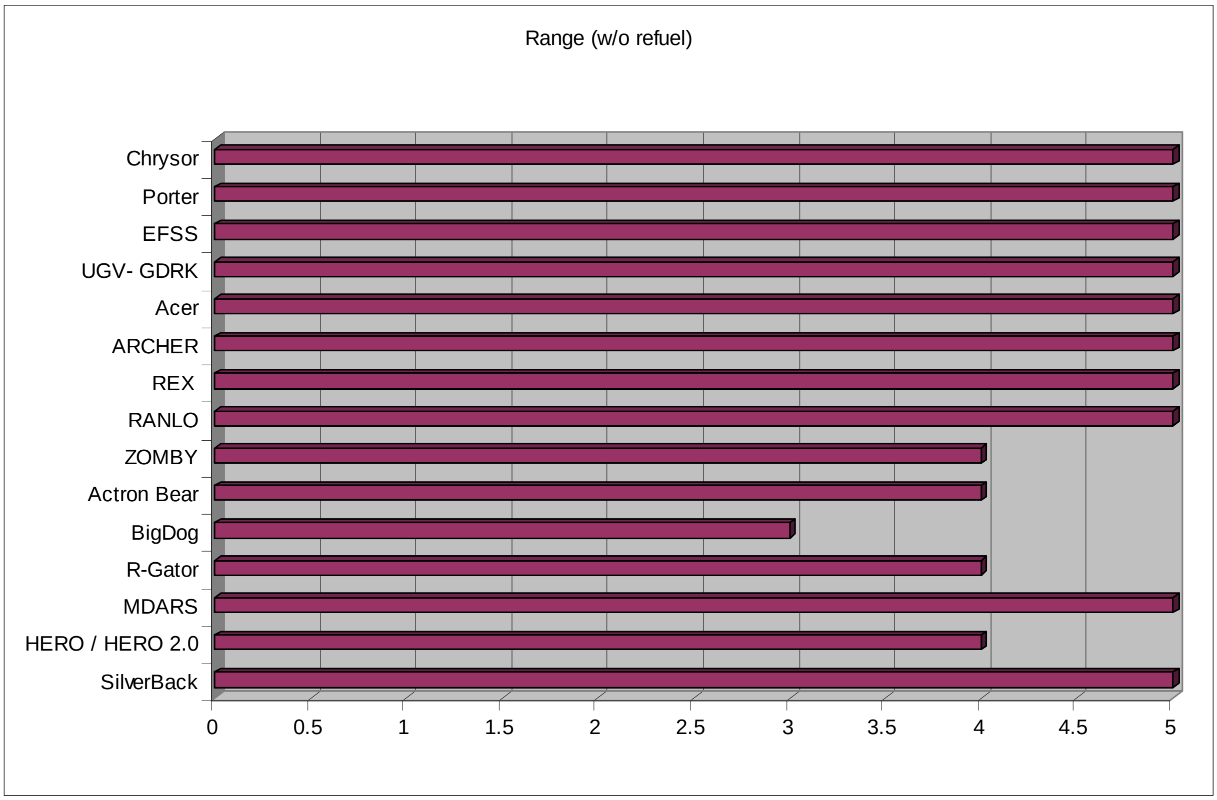


Figure 19. System Range Scores

Autonomy

Within the context of this document, "autonomy" is defined as robotic action without direct human-operator control. This research focused on autonomous operations as they pertained to motion and navigation – for instance, "Can the robot get from point A to point B without being steered by a human operator?" Although it is simple for a human to achieve this task, the UGV requires a specialized suite of behaviors to accomplish this mission. One of the key navigation traits specified by ONR is that of "leader–follower," in which the UGV autonomously follows a dismounted human lead. A variation on this theme is the ability of the UGV to follow another vehicle (manned or unmanned), in essence creating a chain or convoy of vehicles. Table 8 presents the scoring approach for Autonomy and Figure 20 depicts the system scores for this variable.

Table 8. Vehicle Autonomy Scoring

Scoring	1	2	3	4	5
Autonomous Navigation	Pre-programmed Waypoints		Waypoints Plus Obstacle avoidance		Able to "Follow the Leader"

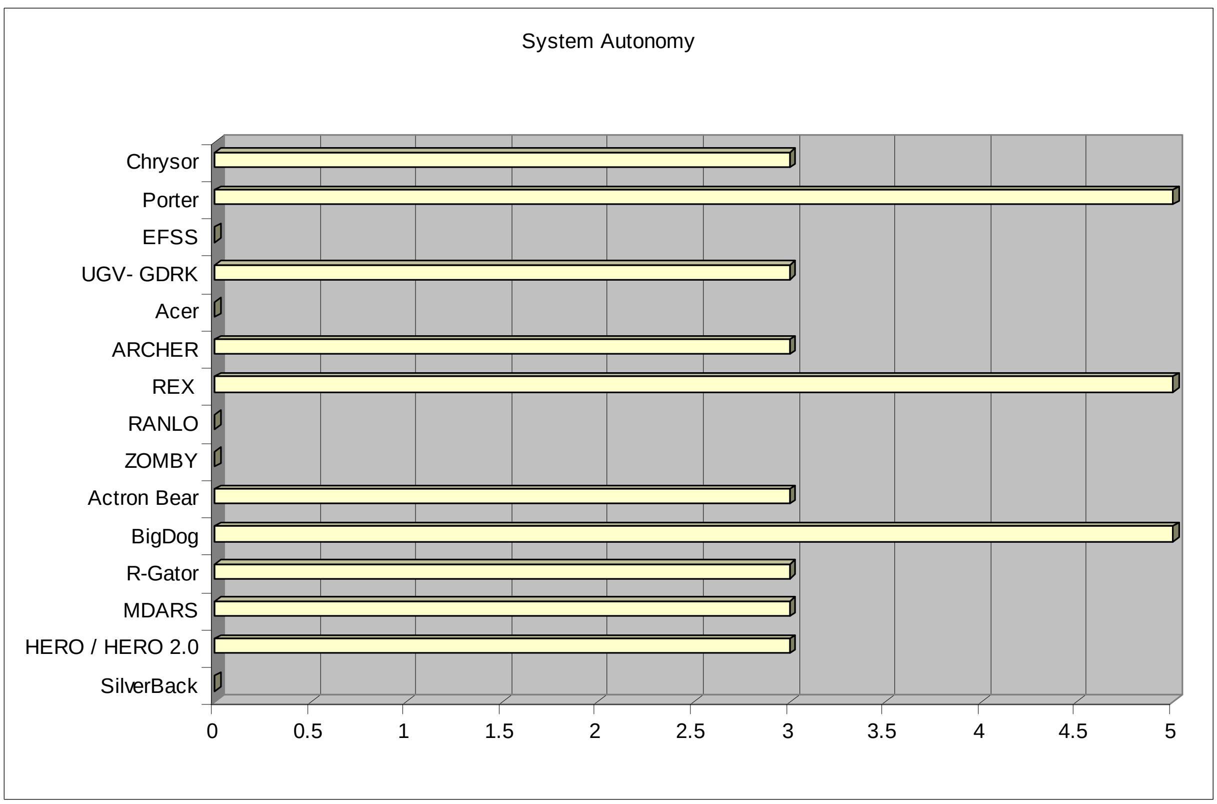


Figure 20. System Autonomy Scores

As described above, a UGV may possess multiple autonomous behaviors, depending on the mission tasking and specific required perception capabilities. Among the types of behaviors and capabilities are the following:

- Navigation
  - Localization
  - Path planning
  - Obstacle mapping and collision avoidance
  - Waypoint following
- Following
  - Road following
  - Vehicle following
  - Dismount (human) following
- Tactical Behaviors
  - Reconnaissance
  - Surveillance
  - Target acquisition
  - Target tracking

A NATO working group reported the following “Vital Gaps” in UGV platform navigation to support military activities (2008):

- Autonomous road following
- Autonomous driving in mixed traffic (max speed of 50 kilometers per hour (km/h))
- Moving in all terrain with tactical behavior in (nearly) all weather conditions
- Following leader (manned or autonomous), any type of vehicle

These behaviors were further separated into the following individual technical issues/challenge categories:

- Obstacle avoidance (static obstacles)
- Obstacle avoidance (dynamic obstacles)
- Route re-planning
- Exception handling
- Traversability
- Spatial cognition
- Self-localization

Follow-the-Leader Behavior

In a teaming relationship between a robot and a dismounted Marine, a key aspect involves joint maneuver. In particular, when conducting operations, the Marine must have knowledge of (and confidence in) the robot’s current location. Typically, the robot will follow the Marine in a prescribed fashion according to the mission or action at hand. The UGV must be capable of target tracking and path planning. Additionally, the system must have strategies (algorithms) for dealing with a lost target as well as target re-acquisition.

Several methods exist for establishing the leader-follower relationship. Nguyen et al. (2004) examined the leader-follower paradigm in creating and testing a small robotic transport system based on the Segway Robotic Mobility Platform (RMP) at SSC Pacific. Nguyen evaluated both the concept of a vision-based and a global positioning system (GPS)-based leader-follower approach.

The RMP system required the visual initialization of the platform-mounted camera and tracking algorithm on the target. Thereafter, the system visually “locked on” to the leader’s torso and commenced a following routine at a prescribed distance. The system was dependent on the visual profile of the leader to assess distance; this led to minor issues when the leader turned sideways (and therefore appeared further away) or when the leader swung his arms (and therefore appeared closer). Laser and/or sonar additions to the visual sensing might help mitigate these problems. A limitation of this particular system is that it requires close tracking and following, subject to visibility conditions.

In the GPS tracking evaluation, the leader emitted a GPS signal, which is received and processed by the following UGV. The follower conducts path planning from the waypoint information to determine direction and distance to the leader. A series of points are used in this process. In essence, this method involves creating a trail of GPS “breadcrumbs.” Limitations of this method include its reliance on GPS positioning, together with the radio link required between the leader and follower to relay the GPS breadcrumb. Another limitation is the slow reaction time to rapid changes in speed and/or direction associated with the lag in waypoint processing and path planning.

More recently, the Boston Dynamics “BigDog” platform used a slightly different approach. Here, the leader is required to wear a reflective vest and the follower (BigDog) uses a SICK LIDAR (light detection and ranging) system to locate the leader. Onboard processing generates a path plan, resulting in BigDog following the leader at a fixed distance. The requirement for a reflective vest is obviously a problem and a distinct liability in a tactical setting. In the Joint Ground Robotics Enterprise (JGRE) Urban Environment Exploration (URBEE) project, SSC Pacific identified a number of modalities to allow a robot to keep station on its human partners: vision (utilizing monocular and stereo optical and thermal cameras), ladar (laser radar), personal odometry, differential GPS, and acoustic. While each individual sensor can track the leader independently with some success, each also has its own characteristic weaknesses. A more robust approach is to intelligently fuse the results from multiple sensors so that when one sensor fails or provides noisy or weak data, the system will rely more heavily on the other sensors.

Communications

Human-robot communication is essential, both for passing instructions (issuing orders) and sharing situation awareness (SA). However, command and control of the unmanned systems must not become a burden. As Everett (2004) noted, “from a command-and-control perspective…the ultimate goal in a tactical environment would be to eliminate the need for a separate robotic controller altogether (at least at the organic level), since it represents an unwanted burden and potential liability for the operator. Today’s warfighters have enough equipment to carry as is, and anything that needlessly distracts them with low-level details can seriously reduce their chances of survival in hostile environments. Currently there is a tradeoff between the value added by the robot (i.e., in terms of how it contributes to the performance of the mission), and the additional burden imposed by the OCU (i.e., how it interferes with the operator’s ability to perform and perhaps even survive).”

Table 9 presents the scoring approach for Communications, and Figure 21 depicts the system scores for this variable.

Table 9. Vehicle Communications Scoring

Scoring	1	2	3	4	5
Communications Capabilities	Wireless communications		Redundant communications (two or more systems)		Responds to a variety of communications (words, whistle, hand-and-arm signals, beacons, etc.)

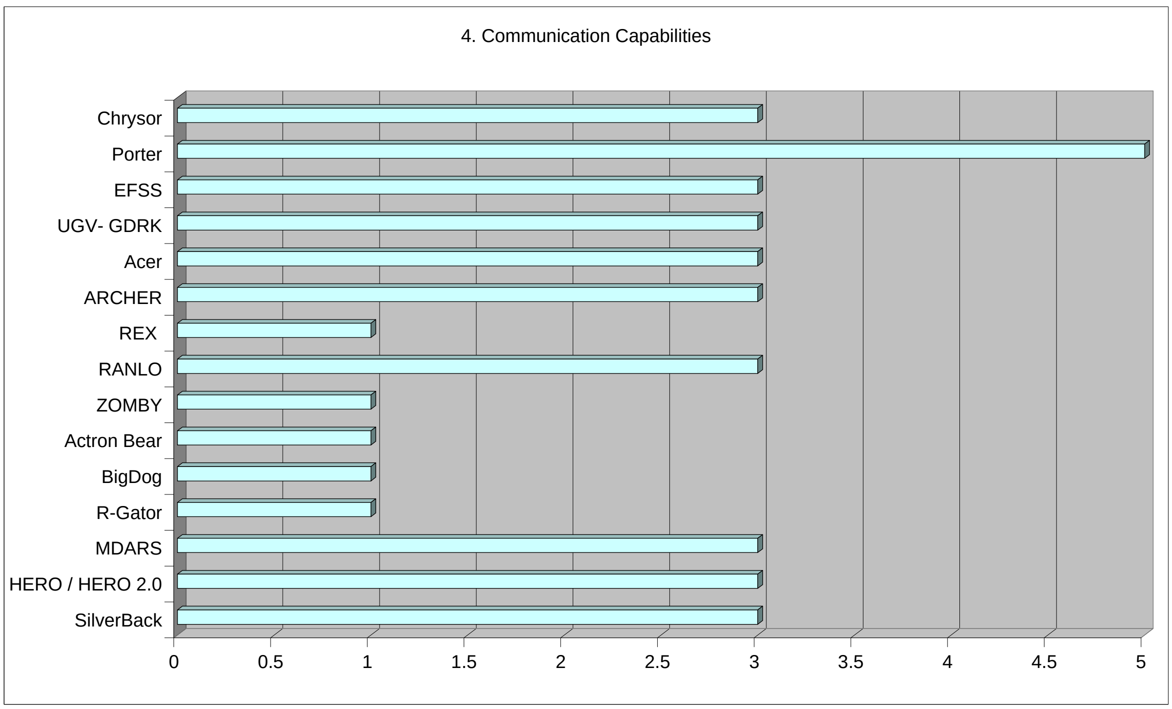


Figure 21. System Communication Scores

Mobility

Maneuver is central to the dismounted Marine. Consequently, the UGV's ability to support the movement requirements of the Marine is essential. In the evaluation of systems, mobility was broken down into four distinct categories involving speed and traversability. The results are presented below.

It is interesting to note that most of the top-scoring UGV's are track- or wheel-based; only the BigDog is a leg-based system. This presented BigDog with certain advantages (particularly involving its ability to traverse terrain similar to that of a human), although its speed suffered compared to the wheeled and tracked platforms and it is still lacking in fuel efficiency, averaging only about 1 mile per gallon of fuel.

Table 10 presents the scoring approach for vehicle Speed, and Figure 22 depicts the system scores for this variable.

Table 10. Vehicle Mobility (Speed) Scoring

Scoring		1	2	3	4	5
Mobility (Part I)	Max Speed	x < 5 MPH	5 ≤ x < 10 MPH	10 ≤ x < 25 MPH	25 ≤ x < 50 MPH	50 ≤ x MPH

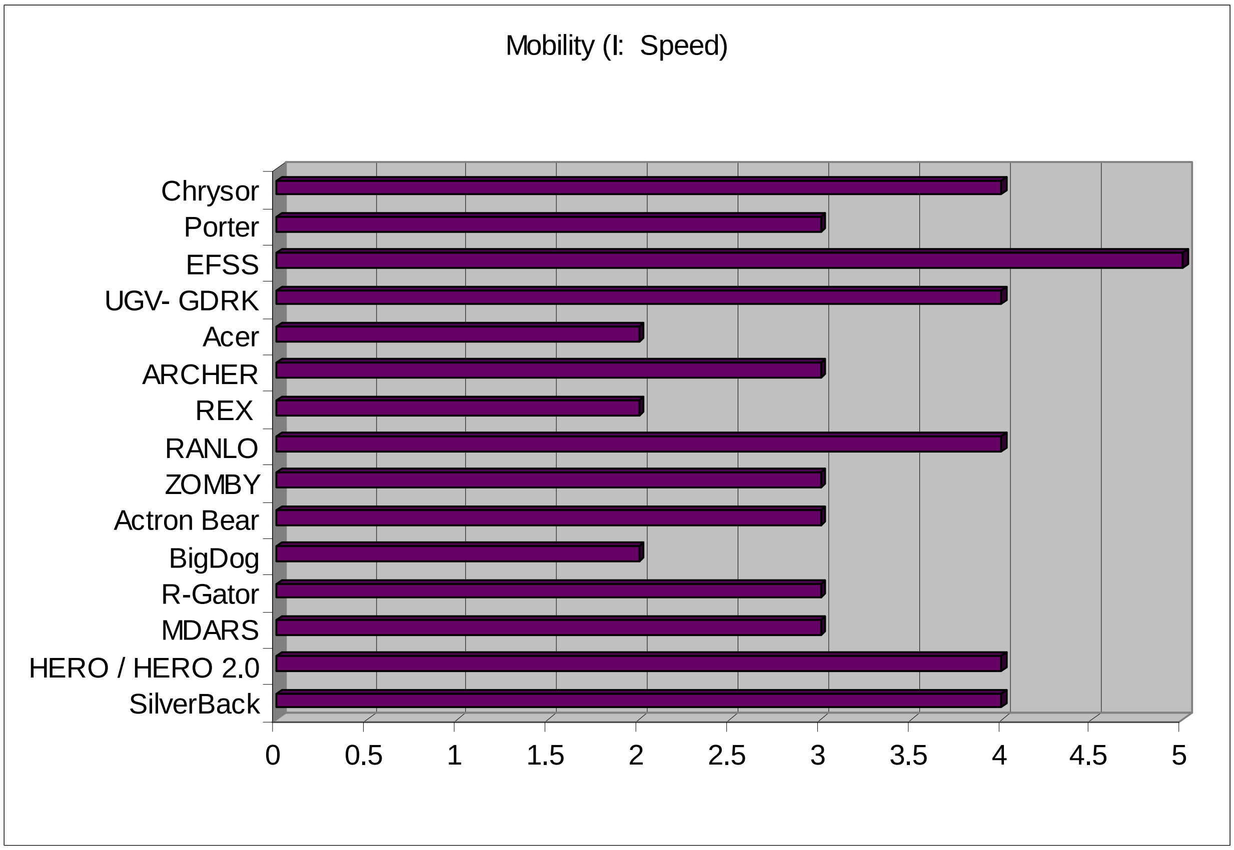


Figure 22. System Mobility (Speed) Scores

Next, we consider systems' ability to traverse vertical obstacles. Table 11 presents the scoring approach for Vertical Obstacle Traversal, and Figure 23 depicts the system scores for this variable.

Table 11. Vehicle Mobility (Vertical Obstacle Traversal) Scoring

Scoring		**1**	**2**	**3**	**4**	**5**
Mobility (Part II)	Able to Traverse	≥12" vertical obstacle	≥18" vertical obstacle	≥24" vertical obstacle	≥30" vertical obstacle	≥36" vertical obstacle

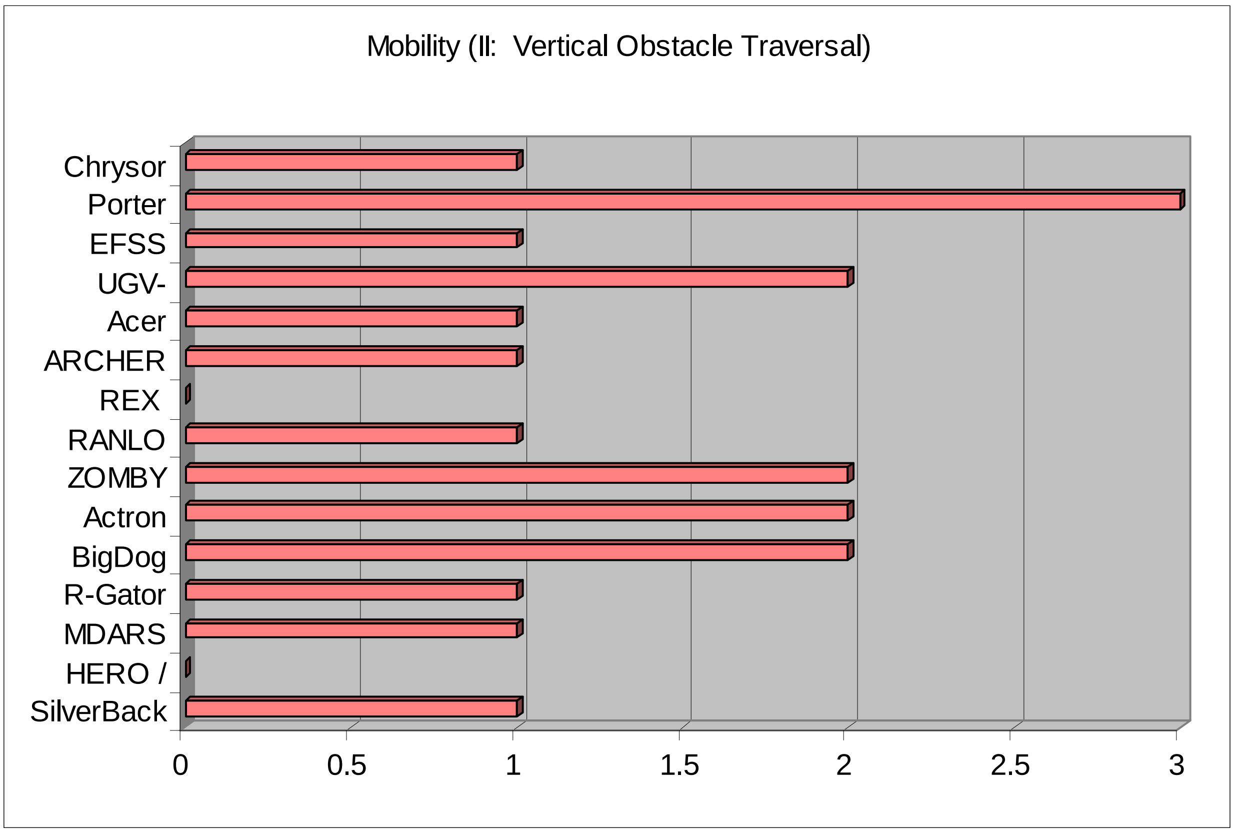


Figure 23. System Mobility (Vertical Obstacle Traversal) Scores

Next under the heading of system mobility, we consider ability of candidate unmanned systems to traverse horizontal obstacles (e.g., ditch-crossing). Table 12 presents the scoring approach for Horizontal Obstacle Traversal, and Figure 24 depicts the system scores for this variable.

Table 12. Vehicle Mobility (Horizontal Obstacle Traversal) Scoring

Scoring		**1**	**2**	**3**	**4**	**5**
Mobility (Part III)	Able to Traverse at speed	Ditches ≥ 12” width	Ditches ≥ 24” width	Ditches ≥ 30” width	Ditches ≥ 36” width	Ditches ≥ 48” width

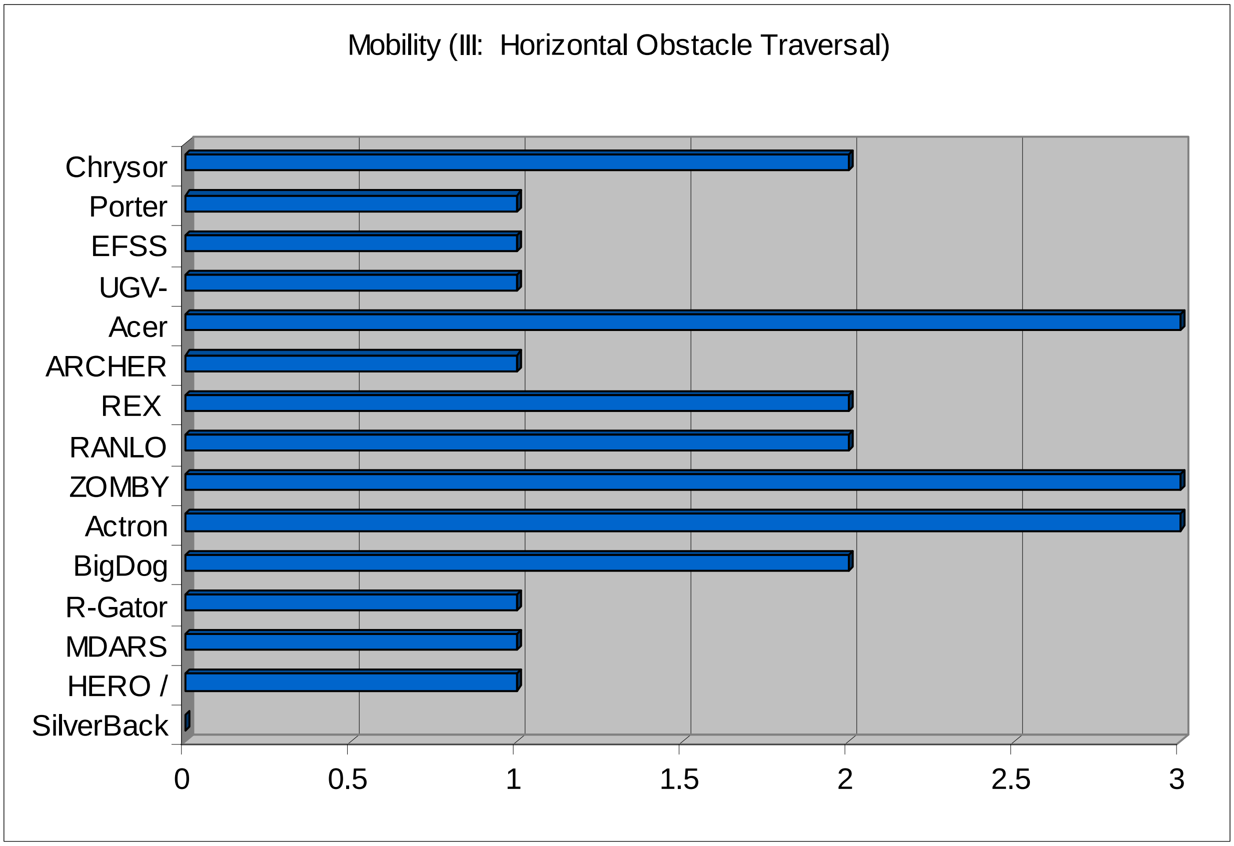


Figure 24. System Mobility (Horizontal Obstacle Traversal) Scores

Finally, under the heading of system mobility, we consider the ability of candidate unmanned systems to traverse water. Table 13 presents the scoring approach for Water Traversal and Figure 25 depicts the system scores for this variable.

Table 13. Vehicle Mobility (Water Traversal) Scoring

Scoring		1	2	3	4	5
Mobility (Part IV)	Able to Traverse Water (Depth)	x < 6”	6” < x ≤ 12”	12” < x ≤ 24”	24” < x ≤ 48”	48” < x

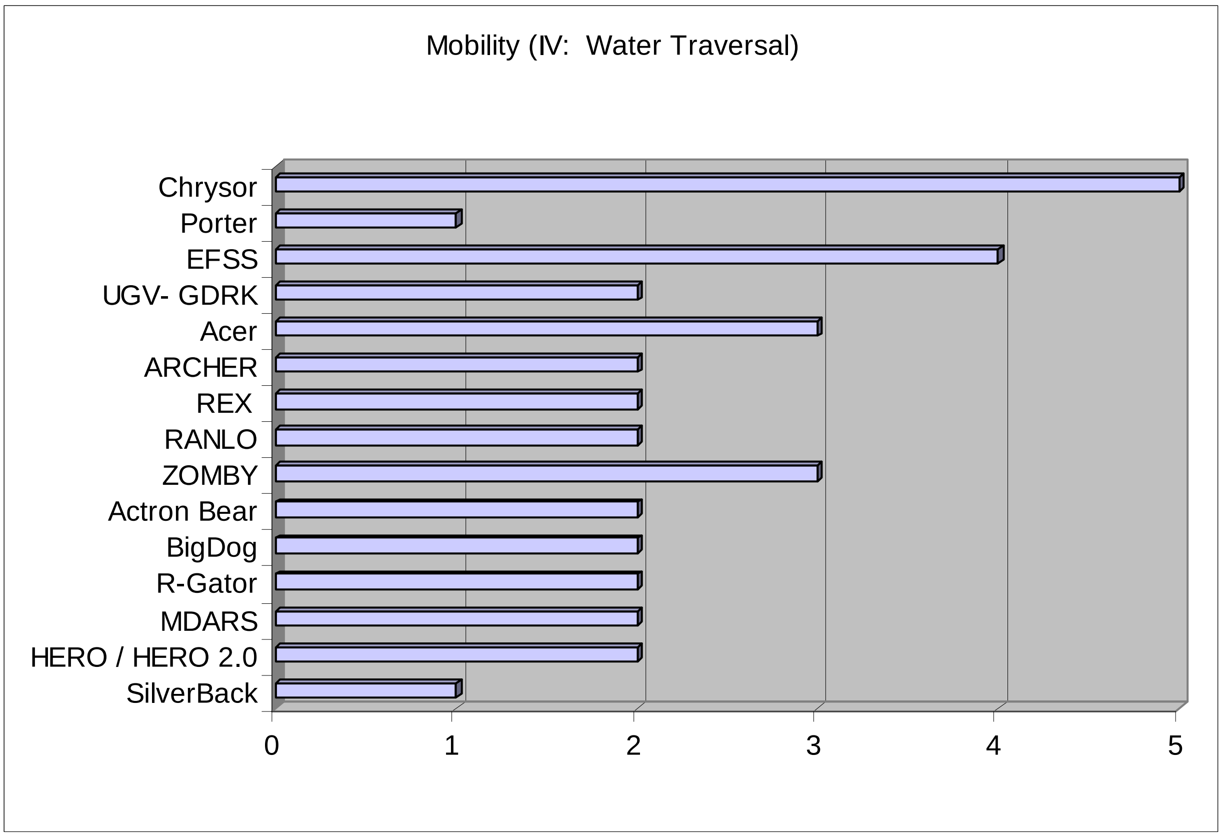


Figure 25. System Mobility (Water Traversal) Scores

Payload Capacity

In order to be of any logistical value to dismounted Marines, the UGV must be capable of carrying a substantial payload. Naturally, the total payload carrying capacity will involve both its own organic equipment (e.g., system sensors) and the Marines' equipment. Table 14 presents the scoring approach for Payload, and Figure 26 depicts the system scores for this variable.

Table 14. Vehicle Payload Scoring

Scoring		1	2	3	4	5
Payload	Lbs	50≤x<70	70≤x<100	100≤x<500	500≤x<1200	1200≤x

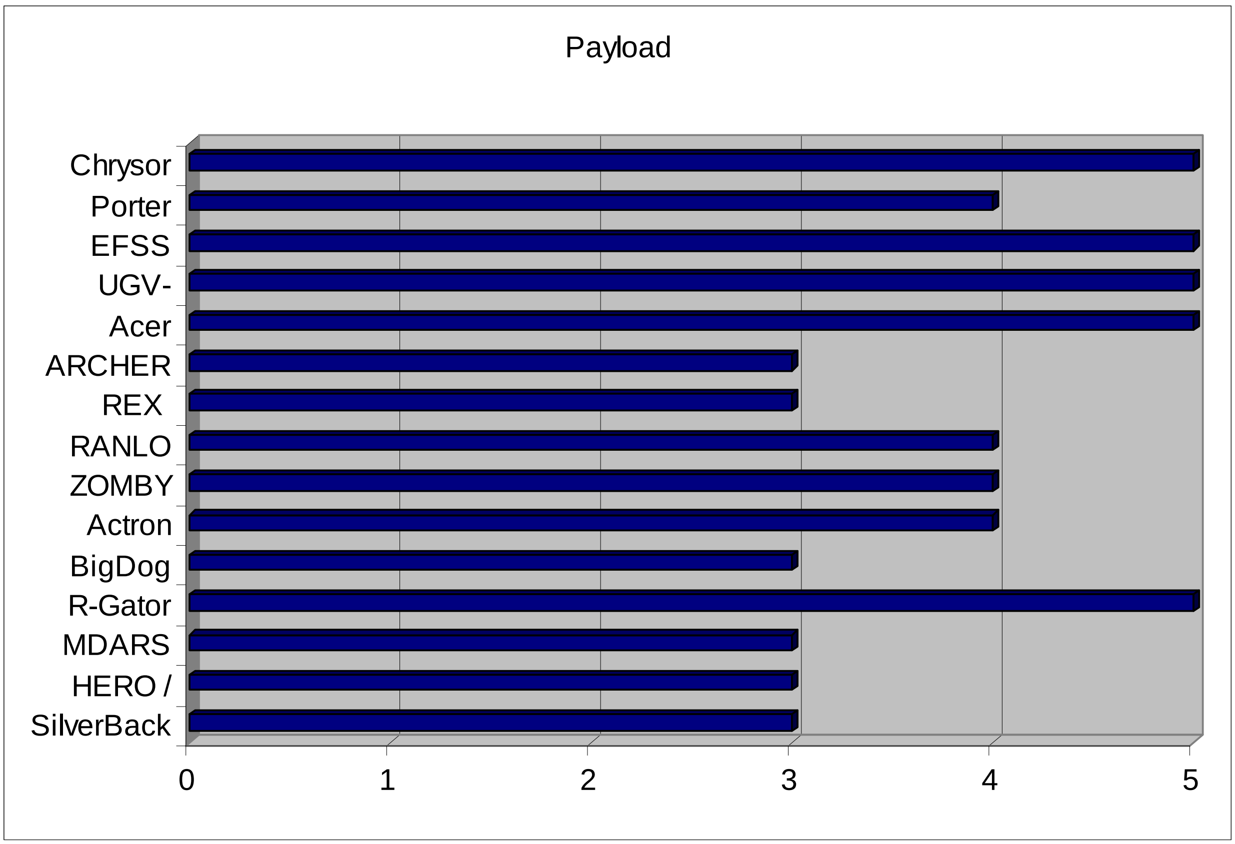


Figure 26. System Payload Scores

Transportability and Recoverability

The final evaluation criteria involved the candidate UGVs' ability to meet Transportability and Recoverability considerations for Marine missions.

In terms of transportability, we were principally interested in the candidate systems' ability to be stowed in, and transported by, a V-22 Osprey. At issue, of course, are system weight and

dimensions. Table 15 presents the scoring approach for Transportability, and Figure 27 depicts the system scores for this variable.

Table 15. Vehicle Transportability Scoring

Scoring		1	2	3	4	5
V-22 internally transportable with system weight of:	Lbs.	1000 ≤ x < 5000 lbs	500 ≤ x < 1000 lbs	200 ≤ x < 500 lbs	100 ≤ x < 200 lbs	x < 100 lbs

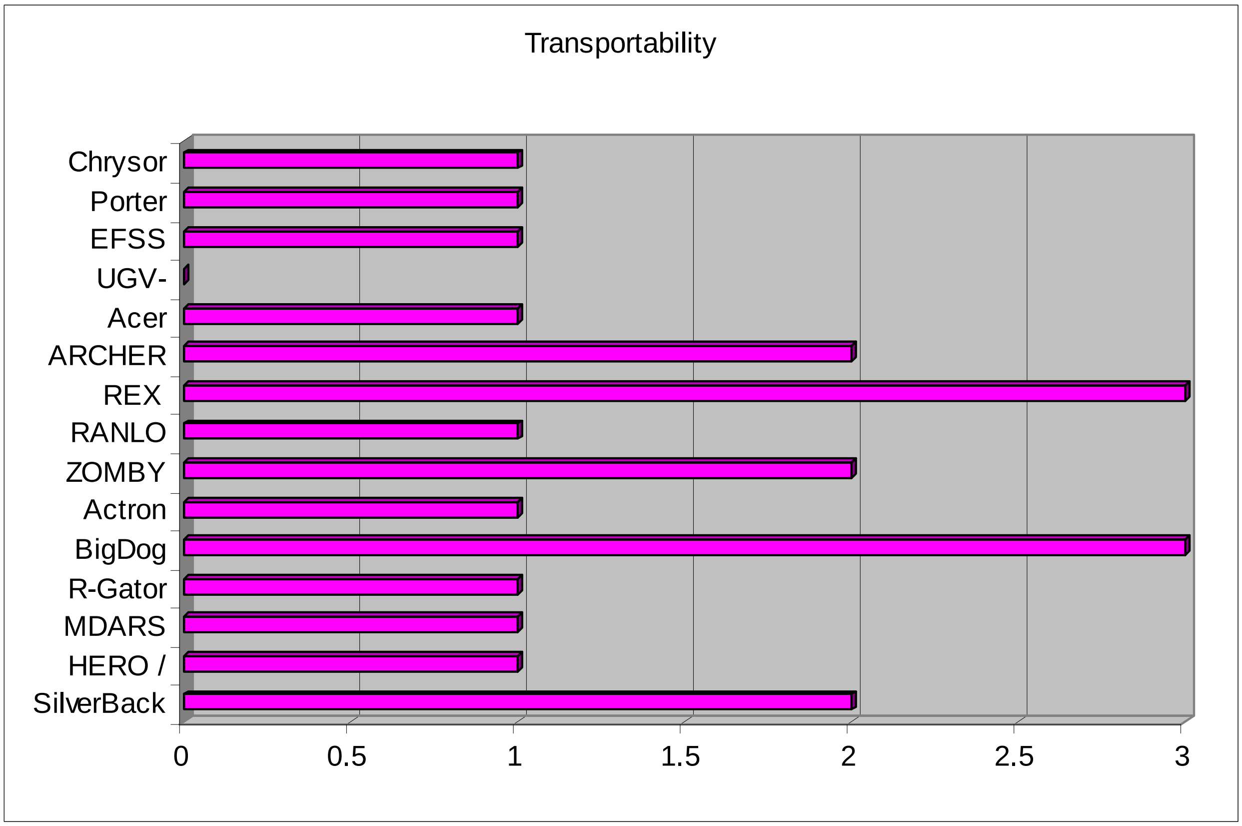


Figure 27. System Transportability Scores

Turning to recoverability, at issue is the situation in which a UGV gets "stuck." The analysis for this variable is divided into two categories: "Small Systems" (i.e., less than 300 pounds) and "Large Systems" (300 pounds and above). For small systems, we are interested in whether the UGV can be lifted and carried by two or four Marines. For large systems, the analysis involved consideration of whether the UGV may be tele-operated and potentially freed from its entrapment. Alternatively, some systems have a "manual" capability in which a driver can climb in or aboard and manually drive the system out of its entrapment. A minimum requirement for both small and large systems is the provision of a winch attachment point.

As it turned out, there were no “small systems” that made it to this phase of the analysis – all of the systems that were considered here weighed a minimum of 300 pounds[8]. Consequently, Table 16 presents the scoring approach for Vehicle Recovery (Small Systems), but there is no corresponding figure depicting systems scores.

The lifting values shown in the table below (< 152 pounds for two Marines; < 295 pounds for four Marines) were derived from MIL-STD-1472F (Table XVII), which specifies that a male can carry an object with a maximum weight of 82 pounds (37.2 kilograms (kg)) for a distance of 33 feet (10 meters (m)) or less.

This figure (82 pounds) was further modified by Dr. Jim Hodgdon of the Naval Health Research Center, who provided the following information (e-mail, 13 August 2009):

> *One additional finding that might be of interest. If the device to be lifted weighs more than one person can manage, the values for team lifting are not simply the single person value multiplied by the number of people. As more people are added to a team, the effective weight lifted by an individual decreases. (see Karwowski & Mital, Ergonomics 1986 29(7):869-878; and Sharp et al Human Factors 1997 39(3):481-488.) Sharp and colleagues find for teams made up of either men or women, the multiplier for a team deadlift, based on individual maximal capacity is 1.85 for a team of 2, 2.52 for a team of 3, and 3.6 for a team of 4. You might need to take this sort of finding into account for your planning.*

Consequently, our two-man lift is 1.85 x 82 pounds (or 151.7 pounds, rounded to 152) and our four-man lift is 3.6 x 82 pounds (or 295.2 pounds, rounded to 295).

Table 16. Vehicle Recovery (Small Systems) Scoring

Scoring		1	2	3	4	5
Recoverability (Small Systems)		Recoverable by Winch		Recoverable by Four 50-Percentile Marines (Weight < 295 lbs)		Recoverable by Two 50-Percentile Marines (Weight < 152 lbs)

[8] Except BigDog, which – at 240 pounds – seemed close enough to treat as a “large system” for recoverability purposes. As it turns out, its score (3 points) is identical whether treated as a “large system” or a “small system.”

Finally, Table 17 presents the scoring approach for Vehicle Recovery (Large Systems), and Figure 28 depicts the system scores for this variable.

Table 17. Vehicle Recovery (Large Systems) Scoring

Scoring		1	2	3	4	5
Recoverability (Large Systems)		Recoverable by Winch		Recoverable by Teleop		Can Get In and Manually Drive Unit

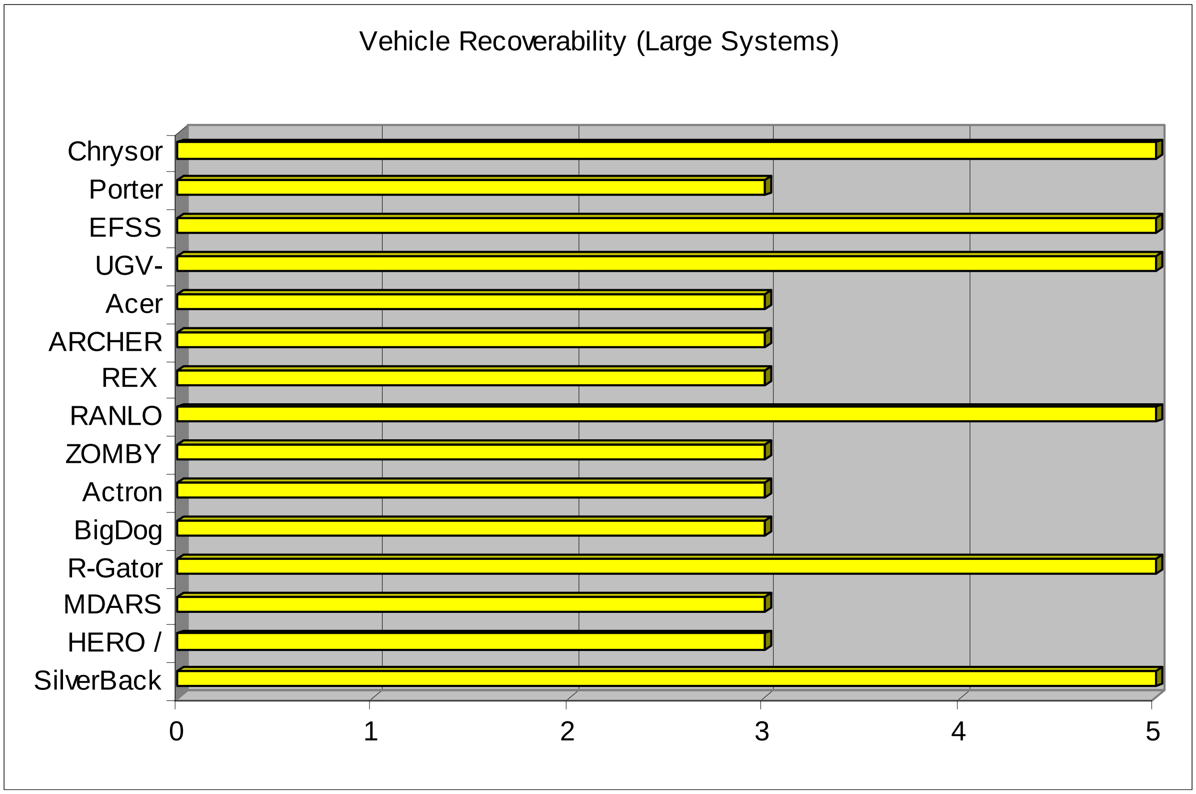


Figure 28. System Vehicle Recovery (Large Systems) Score

SECTION IV. CANDIDATE SYSTEM PROFILES

Following the data culling and system ranking, described in previous sections, the top 15 systems were selected for additional review. Consequently, System Profiles are provided for these systems, in order of overall scoring (Figure 2), and are depicted on the following pages.

- **Chrysor** (Robowatch Technologies GmbH)
- **Porter** (Vecna Technologies, Inc.)
- **Growler EFSS** (Expeditionary Fire Support System) (American Growler, Inc.)
- **Unmanned Ground Vehicle (UGV) Safe Operations (Safe Ops) T2** (General Dynamics)
- **Acer** (Mesa Robotics)
- **Archer / Archer BATTLEWAGON** (Elbit Systems of America)
- **Rex – Infantry Robotic Porter** (Israel Aerospace Industries, Ltd.)
- **Ranlo** (Defense Technologies, Inc.)
- **Zomby** (Invenscience LC)
- **Actron Bear** (AcroTek, Inc.)
- **BigDog** (Boston Dynamics)
- **R-Gator Large-Wheeled Logistics and Patrol UGV** (iRobot / John Deere)
- **Mobile Detection Assessment and Response System (MDARS)** (General Dynamics)
- **Hero / Hero 2.0** (Radiance Technologies, Inc.)
- **SilverBack** (Codarra Advanced Systems Pty Ltd)

At this point, a caveat is in order. Much of the information that we acquired and utilized in performing our reviews and analyses has been self-reported or proprietary in nature, i.e., from the individual companies themselves. While we have continually sought open-source and unbiased third-party reporting, it cannot be over-emphasized that many of the performance and capability claims, at this point, have not been substantiated by unbiased sources. As we will stress again later in this report, a systematic, side-by-side operational test and evaluation is essential to establish a level playing field, evaluate key operational parameters, and separate marketing hype from actual operational capability.

Chrysor

System Name: Chrysor

Manufacturer: Robowatch Technologies GmbH

Country: Germany

Rank: 1/15

Score: 35/55 Points

1 Pan-and-tilt camera sytem

2 Telescopic arm

3 CCD-zoom camera with image stabilization

4 Thermal imaging camera

5 DGPS antenna

6 AdHoc WLAN antenna

7 Cameras for 360° panoramic views

8 Access to driver's cabin

9 3D laser for navigation

10 Xenon spotlights

Strengths: Range; Mobility (Speed, Water Traversal); Payload; Recoverability (Can Be Winched, Towed, or Driven)

Weaknesses: Mission Duration; Mobility (Vertical Obstacle Traversal); Transportability (Weight = 2,095 pounds)

Website: http://www.robowatch.de/index.php?id=303

General Discussion: Chrysor

Robowatch Technologies GmbH is a manufacturer of Unmanned Ground Vehicles for EOD, improvised explosive device (IED), border patrol, reconnaissance, and chemical, biological, radiological, nuclear, and high-yield explosives (CBRNE) detection with substantial experience in the international arena. (Robowatch delivered 16 robots to Beijing for security during the 2008 Olympics.)

Robowatch developed the CHRYSOR using the Centaur (an 8x8 all-terrain utility vehicle manufactured by ARGO/Ontario Drive and Gear in New Hamburg, Ontario) as the base platform. The CHRYSOR is a reconnaissance and transportation vehicle capable of performing its functions with or without a driver. In driverless mode, it can either operate autonomously or be tele-operated from a central control location.

With its 360° panoramic capability, a telescopic observation arm, and current sensor technology, CHRYSOR is able to scan its surroundings, detecting moving objects or hazardous substances.

A key feature of this vehicle is its modular design. With a payload of up to 680 kg (approximately 1,500 pounds), the CHRYSOR can be equipped with additional mission modules or add-on components and configured to meet mission-specific requirements. It can either be operated manned or unmanned and perform a variety of roles, including reconnaissance, serving as a remotely controlled lead vehicle in convoys, as a transportation (logistics) vehicle, or medical missions.

In addition to its 8-wheeled configuration, the CHRYSOR can optionally be configured with a tracked drive.

The CHRYSOR offers reasonably good mobility, a substantial available payload, and basic autonomy. It is unusually flexible in terms of its operational modes (it can operate autonomously, be tele-operated, or manually driven) and it offers both wheeled and tracked configurations.

Porter

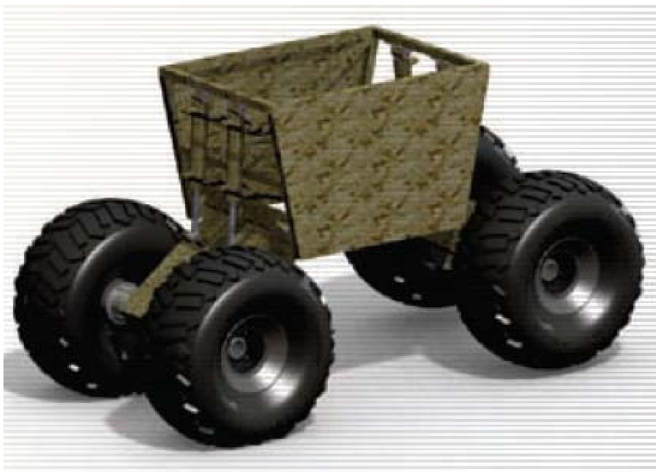
System Name: Porter

Manufacturer: Vecna Technologies, Inc.

Country: U.S.A.

Rank: 2/15

Score: 32/55 Points



Strengths: Range; Autonomy; Communications Capabilities; Payload

Weaknesses: Mission Duration; Mobility (Ditch and Water Traversal); Transportability (Weight > 1,000 pounds)

Website: http://vecnarobotics.com/solutions/porter.shtml

General Discussion: Porter

Founded in 1999 by MIT alumni, Vecna Technologies is a high-technology company with offices in Cambridge, MA, Greenbelt, MD, Falls Church, VA, and Silicon Valley. According to Wikipedia, the founders derived the name “Vecna” from the Czech word věčný meaning ‘eternal,’ implying that the company and its products are built to last.

Incidentally, it is worth mentioning that the Porter has received far less press than the Vecna “Bear” (short for “Battlefield Extraction-Assist Robot”). Although we reviewed the Vecna “Bear,” it did not score highly enough for further analysis here.

Vecna intended the Porter to address medium-size military transport, logistics and mission support, filling the gap between personal LBE (load-bearing equipment) systems and standard military transport solutions where medium load carrying capabilities (200-600 pounds) are required. The vehicle is built to negotiate off-road terrain while maintaining attitude control and vibration or shock isolation on sensitive loads.

Optional full and semi-autonomous control allows for several modes of operation. Users may control the vehicle directly using the remote interface; alternatively, the vehicle may be placed into “Follow Me Mode,” where it maintains a specified distance from the operator on the move. With an additional navigation package, the Porter can also operate in fully autonomous mode, including path planning, terrain mapping, and navigation. Consequently, according to Vecna, several Porter vehicles can be used in an autonomous convoy, perform cooperative perimeter surveillance, etc. The vehicle's base unit may be configured to carry various types of payloads and the chassis can be tailored to meet the specific requirements of the mission.

Other potential uses for the Porter include carrying gear in a variety of terrains; serving as an autonomous sentry; performing relatively short distance transport and material handling; and serving as a powered stretcher or evacuation vehicle (which, interestingly, would seem to encroach somewhat on the “Bear’s” turf).

Available options include a “Semiautonomous package” (permitting load balancing, follow me mode, and convoy operations), an “Autonomous package” (permitting GPS navigation, path planning, and terrain mapping), and a “Surveillance package” (including cameras – visual spectrum and IR – permitting cooperative patrol, etc.). According to Vecna, prices for the Porter start at $25,000.00.

Vecna took the Porter to the Ground Robotics Obstacle Course at the 28th Annual Modern Day Marine Military Exposition at Quantico, Virginia in September-October 2008, which was co-sponsored by the Marine Corps Systems Command (MARCORSYSCOM) and Marine Corps Base, Quantico (and where it participated along with entries from Applied Perception, Inc.; Elbit Systems Ltd.; iRobot Corporation; and Foster-Miller, Inc.).

Growler / EFSS / ITV

System Name: Growler (Expeditionary Fire Support System/Internally-Transportable Vehicle)

Manufacturer: American Growler, Inc.

Country: U.S.A**.**

Rank: 3/15

Score: 31/55 Points

Strengths: Range; Speed; Payload; Mobility (Water Traversal); Recoverability

Weaknesses: Mission Duration; Autonomy; Mobility (Vertical Object and Ditch Traversal); Transportability (Weight = 4,536 pounds)

Website: http://www.capitaldefense.com/AmericanGrowler.shtml

General Discussion: Growler

The American Growler, or ITV (internally transportable vehicle), is occasionally referred to as an updated version of the M151 Jeep that the U.S. military retired in the early 1980s. It is narrow enough to fit in the V-22, although this may cause stability issues since narrow vehicles are subject to rollover. (The initial Growler was set to be redesigned with a lower center of gravity to help mitigate that problem.)

According to a Marine Corps spokesman, portraying the Growler as a rebuilt Jeep is misleading; despite its similarity in appearance to a Jeep, none of the critical systems are old Jeep parts. The engine, transmission, differentials, drive line, electrical and cooling systems, suspension, brakes and all other critical components are all said to be current technology.

Both the ITV and the EFSS systems are in production, and both systems are in the process of being fielded to units at Camp Lejeune, North Carolina. The ITVs reached Camp Lejeune on 26 January 2009.

The ITV can carry four Marines and either a .50-caliber machine gun or 40mm Mark 19 grenade launcher. Key advantages to the Growler are its internal transportability in the V-22, its speed, and its payload capabilities. However, it is comparatively heavy and, in its current configuration, it lacks any autonomous capability.

No discussion of the Growler would be complete without mentioning that it was the center of an Inspector General audit and report, prepared in response to a request from Senator Carl Levin, Chairman, Senate Committee on Armed Services, who had been contacted by Rae-beck Automotive, LLC (Limited Liability Company), of Sterling, Michigan, a competitor in the process.

The report (No. D-2009-041, Project No. D2008-D000AB-0091.000) of 14 January 2009 offered the following key findings regarding the EFSS and ITV programs:

> “Although our audit did not substantiate most of the constituent’s concerns, we found problems with EFSS and ITV program management and contract award. The Marine Corps Milestone Decision Authority approved the entrance of the EFSS and ITV programs into the Production and Deployment Phase (Milestone C) before the systems had demonstrated acceptable performance in developmental test and evaluation. As a result, the schedule for initial operational capability has slipped 22 months for the EFSS and 17 months for the ITV, while the average unit cost has risen by 86% for the EFSS and by 120% for the ITV. However, the Marine Corps has corrected most EFSS and ITV technical problems as reflected in 2008 operational test and evaluation effectiveness determinations.
>
> “The Marine Corps Systems Command did not award the EFSS and ITV contract in accordance with the Federal Acquisition Regulation. Specifically, Command source selection personnel did not adequately document and disclose all technical evaluation criteria in the solicitation and did not prepare a price negotiation memorandum. As a result, the Command’s source selection decision did not meet Federal Acquisition Regulation tests of fairness, impartiality, and equitable treatment. The Marine Corps Systems Command internal controls were not adequate. We identified internal control weaknesses over contract competitions and the acquisition system’s program planning and execution process.”

UGV Safe Ops T2

System Name: Unmanned Ground Vehicle Safe Operations T2

Manufacturer: General Dynamics Robotics Systems

Country: U.S.A**.**

Rank: 4/15

Score: 31/55 Points

Strengths: Range; Speed; Payload; Recoverability

Weaknesses: Mission Duration; Mobility (Vertical Object, Ditch, and Water Traversal); Transportability (Weight = 2,000 pounds)

Website:
http://www.gdrs.com/admin/robotics_quarterly/rqpdf/May%202008%20RQ6%20Final%20LRes.pdf

General Discussion: UGV Safe Ops T2

Formed in 1952, General Dynamics has been around for over a half-century, occasionally reforming itself as it has changed its product focus. General Dynamics Robotics Systems (GDRS) was founded in 1991 as Robotics Systems Technology, a developer and integrator of robotic vehicle and control capabilities.

In addition to the present Market Survey, GDRS mentioned that it has previously responded to other Market Surveys, including requests from the Marine Corps Warfighting Laboratory (MCWL) and in support of the recent MCWL Enhanced Company Operations Limited Objective Experiment, in which a GDRS-equipped High Mobility Multipurpose Wheeled Vehicles (HMMWV) provided unmanned logistics support to small units engaged in tactical operations.

The General Dynamics Second Generation Tactical Autonomous Combat-Chassis (T2) is based on a low-cost, readily maintainable industry-standard design. It uses sensors to maintain situational awareness in cluttered and dynamic environments and has the ability to not only track obstacles but to detect, track and predict in which direction a dynamic obstacle is heading. This ability helps to verify whether obstacles are friend or foe. It can be equipped for manual, teleoperated, semi-autonomous, or autonomous operation.

The T2 consists of an off-road chassis with a lightweight body able to traverse rough terrain, supporting a variety of payloads to handle a range of mission profiles. Among the optional payloads that GDRS offers to customize the T2 for mission-specific applications are the following:

- GDRS' tele-operation kit converts T2 into a fully capable remote platform, giving the operator control over every aspect of the missions from a separate vehicle or location
- Advanced robotic sensor, perception and hazard/human detection payloads provide 360-degree visibility day or night in all weather conditions
- Robotic manipulators
- Smoke generators and weapon launchers
- Modular options transform T2 for medevac, supply and logistics, and troop transport assignments.

Besides the T2 itself, GDRS developed the GDRS Robotics Kit (GDRK) as an add-on system that turns manned ground vehicles into unmanned robotic systems. According to the manufacturer, the GDRK allows any tactical vehicle to become robotically controlled while maintaining its ability to be manned. It is a modular kit that has been integrated onto HMMWV, Light Medium Tactical Vehicle (LMTV), Stryker, Husky and several commercial automotive platforms.

Acer

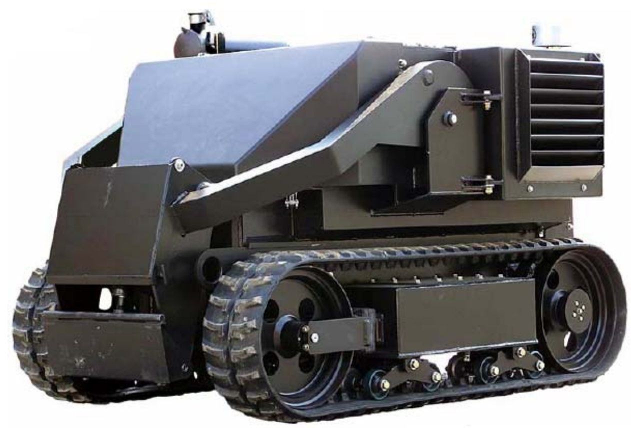
System Name: Acer

Manufacturer: Mesa Robotics

Country: U.S.A.

Rank: 5/15

Score: 29/55 Points

Strengths: Range; Payload

Weaknesses: Autonomy; Mobility (Vertical Obstacle Traversal); Transportability (Weight = 4,500 pounds)

Website: http://www.mesa-robotics.com/acer.html

General Discussion: Acer

Among the family of robots offered by Mesa Robotics, Inc. of Madison, Alabama, the Acer stands out in the same way a Great Dane stands out in a pack of Chihuahuas. The other Mesa Robotics offerings – the “Matilda,” “Element,” “Scorpion,” and “G2Bot” – are small, Packbot-sized UGVS. The Acer, on the other hand – at 83” (L) x 62” (W) x 56” (H) and 4,500 pounds – is a large, hulking system that looks like a bulldozer and suggests brute strength. With its 62 horsepower diesel engine, 2,500 pound payload capacity, 25,000 pound towing capacity, and armor, this appearance of strength seems to be substantiated. The name “Acer” is short for “Armored Combat Engineer Robot.”

The Acer can be configured to handle a variety of tasks. In an EOD role, it can clear out explosives with a mechanical arm or roll along with a mine-sweeper attached to the front. Additionally, it can clear a path or cut through obstacles with a plow blade or a giant cutter, pull disabled vehicles (up to and including buses), haul cargo in a trailer, and serve as a weapons platform. It can also serve as a firefighting / decontamination platform. The system itself has a 1,000-pound lift capacity and a 1600-square-inch payload area.

For the past couple of years, Mesa Robotics, Inc., has partnered with Raytheon in a Mentor-Protégé program sponsored by the Department of Defense. The Acer is listed in the Federal Emergency Management Agency “Responder Knowledge Base.” According to Mesa Robotics, Rafael Advanced Defense Systems, Ltd. in Haifa, Israel has had operational experience with the Acer.

Although it may be teleoperated, the Acer currently lacks any inherent autonomous capability.

Archer

System Name: Archer

Manufacturer: Elbit Systems of America

Country: U.S.A.

Rank: 6/15

Score: 29/55 Points

Strengths: Range; Speed; Payload

Weaknesses: Communications; Mobility (Vertical and Ditch Obstacle Traversal); Transportability (Weight = 500 - 1,200 pounds)

Website: http://reflexxrobotics.com/products/platforms/archer

General Discussion: Archer

The Archer ("Advanced Remote-Controlled Hybrid Experimental Robot") and Archer Battlewagon UGVs were submitted by Elbit Systems of America, located in Fort Worth, Texas. (Elbit Systems Ltd. is an Israeli company.) However, the Archer platforms themselves are manufactured by Reflexx Robotics of Riverside, California.

The Archer is currently in production and several variants are on the drawing board. Elbit Systems submitted the Archer "Battlewagon" variant for consideration, in addition to the standard Archer.

The standard Archer weights 500 pounds (the Battlewagon is 1,200 pounds) and employs a Hybrid charging / power system. A small gasoline (or diesel) engine runs a 50-amp alternator to charge the on-board batteries and power any additional installed payload. Consequently, the drive, braking, and steering systems are 24-volt all-electric. The Archer has a 200-pound payload (the Battlewagon payload is 600 pounds), with a 6-foot square payload mounting surface employing an "8020.net" rail system for flexibility.

The Archer is built using commercial off-the-shelf components, including a square steel tube chassis, an all-terrain vehicle (ATV)-based suspension, and 16x8-7 tires.

The Battlewagon is intended to serve as a support vehicle for up to ten dismounted Marines or soldiers, capable of reducing each individual's load by as much as 50 to 80 pounds, including water, individual equipment, batteries, ammunition, communications equipment, first-aid gear, etc. As with the standard Archer, the Battlewagon will employ a hybrid diesel-electric power-plant with electric "silent drive." It will have 4-wheel drive, 4-wheel steering, off-road suspension, and dual electric-drive motors.

In addition to tele-operation, the Archer is semi-autonomous, able to navigate via GPS waypoints with obstacle avoidance. (In GPS-denied environments, the system can navigate via compass heading and distance). According to Reflexx Robotics, hand gesture or voice command "follow me" mode will be possible for the Battlewagon. It will be capable of following on an "invisible leash" as well as being "Train-Linked" as unmanned logistic vehicles, carrying supplies from point to point.

Rex

System Name: Rex Field Robotic Porter

Manufacturer: Israel Aerospace Industries, Ltd.

Country: Israel

Rank: 7/15

Score: 28/55 Points

Strengths: Range; Autonomy

Weaknesses: Communications; Mobility (Vertical Obstacle Traversal)

Website: www.iai.co.il

General Discussion: Rex

The Rex Field Robotic Porter is being developed by Israel Aerospace Industries (IAI), Ltd., located at Ben-Gurion International Airport, Tel Aviv, Israel. It is expected to be a product within 1 year.

Israel Aerospace Industries' purpose for the Rex is to address a critical warfighting dilemma. While technologically advanced nations increasingly seek to supply their warfighters with advanced combat gear, the inescapable result is that soldiers and Marines are obliged to carry this new and improved equipment into battle with them.

The Rex is a robotic platform intended to escort a small unit consisting of 3-10 soldiers or Marines on various types of missions. It is designed to automatically follow the unit, requiring minimal attention from its operator. Consequently, it achieves the objective of NOT increasing the operator's cognitive workload.

According to the manufacturer, the main goals of the Rex Field Robotic Porter are as follows:

- Make new and advanced technologies available to warfighters in the field *without* creating a new load for them to carry
- Decrease the weight and volume of the load that warfighters currently carry in the field
- Improve overall equipment cost effectiveness – the Field Porter makes it possible to use existing systems and payloads; since the platform will carry them, it is possible to decrease the emphasis on the expensive miniaturization of components
- Minimize development risks – REX is based on existing and proven technology that IAI has already successfully implemented on other robotic projects, integrating robotic technologies that exist today

The Rex payload (400 pounds) is equal to its gross vehicle weight. IAI describes the autonomous capabilities of the Rex as being "based on canine training," including "Follow Path" (in which the system follows its leader walking path in both line-of-sight and non line-of-sight conditions) and "Come / Go To" (in which the system can exchange its leader upon demand).

Ranlo

System Name: Ranlo

Manufacturer: Defense Technologies, Inc.

Country: U.S.A.

Rank: 8/15

Score: 28/55 Points




Strengths: Range; Speed; Payload; Recoverability

Weaknesses: Mission Duration; Autonomy; Mobility (Vertical Obstacle Traversal); Transportability (Weight = 1,000 pounds)

Website: http://www.dtiweb.net/index.html

General Discussion: Ranlo

The Ranlo – named after Defense Technologies, Inc.'s (DTI) first location in Ranlo, North Carolina) – is a system capable of wheeled or tracked locomotion and was recently demonstrated as part of the 5th Biennial Unmanned Systems Demonstration in August of 2009 at the Naval Air Station Patuxent River's Webster Field Annex. The demonstrations were a prelude to the Association for Unmanned Vehicle Systems International North America 2009 conference at the Walter E. Washington Convention Center in Washington, D.C.

The Ranlo is based on the Max II (two passenger) All-Terrain Vehicle, built by Recreative Industries, Buffalo, New York. It is a multi-mission platform that supports a number of payloads and offers an amphibious capability.

As can be noted in the pictures, the Ranlo does not have a great deal of ground clearance (just eight inches), which tends to limit its maneuverability in off-road situations. However, unlike many of the systems we reviewed, it is amphibious and capable of fording rivers while carrying a payload (although the amphibious payload will, no doubt, be somewhat less than its normal ground payload of 500 pounds).

Among the Ranlo's greatest attributes are its range and speed – 100 miles and greater than 25 mph, respectively, according to DTI – figures that are among the best of the systems reviewed. It employs a 16-horsepower Briggs and Stratton engine.

In its current incarnation, the Ranlo is a purely tele-operated system, although DTI indicates that system autonomy (including waypoint navigation and obstacle detection) is currently under development.

Zomby

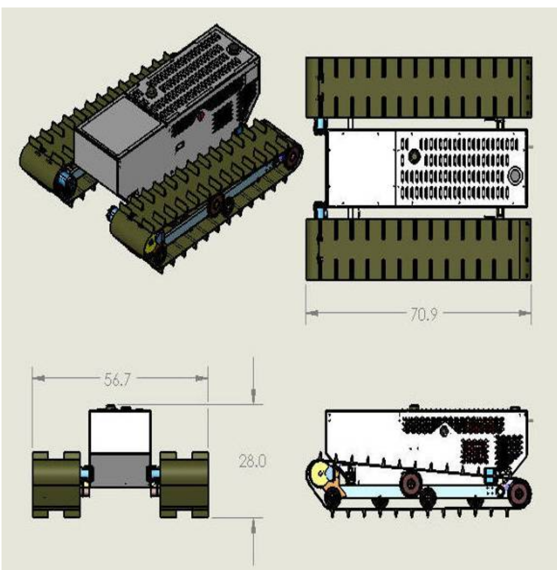
System Name: Zomby

Manufacturer: Invenscience LC

Country: U.S.A.

Rank: 9/15

Score: 28/55 Points



Strengths: Range; Payload

Weaknesses: Autonomy; Communications

Website: http://www.invenscience.com/ZOMBY%20UGV.htm

General Discussion: Zomby

Invenscience LC,[9] located in Nibley, Utah, builds one robotic vehicle (the Zomby) and a 6-DOF (degrees of freedom) robotic arm. Invenscience LC, an electromechanical design solutions provider and components supplier for the unmanned vehicle community, is a relatively new company which began operations in April of 2008 as a spin-off from Lite Trax LC of Logan, Utah.

With a COTS drive train – including a gasoline (670-cubic-centimeter (cc) 2-cylinder, 24-horsepower, 4-cycle Honda) engine – the Zomby is a tele-operated system with no autonomous capabilities. It is a lightweight, low-ground-pressure unmanned ground vehicle with the ability to "tread lightly" due to its large track area. Ground pressure is < 0.25 psi unladen and 0.5 psi at full payload. Consequently, one of its strengths is an ability to operate in soft snow, slush or powder as well as in fine sand or marshy soil, mud, and pavement. According to Invenscience, the Zomby can ford water up to 16" (or more with "simple design changes").

The fuel tank carries enough fuel to travel 45-75 miles, depending on terrain. Six hard points make it possible to attach up to 700 pounds of payload and equipment – exceeding its own vehicle weight of 640 pounds. The Zomby also has a 1,000-pound towing capacity.

Invenscience states that the Zomby is a production item with 50 units in current use and thousands of hours of combined experience. Suggested applications include: research platform; military defense disposable work horse (mine detection, reconnaissance, training, testing, and logistics); recreation; rescue; law enforcement; and agriculture.

[9] LC = Limited Company, in essence, the same thing as LLC (Limited Liability Company)

Bear

System Name: Bear

Manufacturer: AcroTek, Inc.

Country: U.S.A.

Rank: 10/15

Score: 27/55 Points

Strengths: Range; Payload

Weaknesses: Mission Length; Communications; Transportability (Weight = 1,800 pounds)

Website: http://www.acrotek.com/Robotic_Products.htm

General Discussion: Bear

The Actron Bear is manufactured by Acrotek, Inc., which has offices in Dallas, Texas and San Diego, California. Acrotek was established in 1978 and, therefore, has been around longer than many of the firms that we have investigated.

As can be seen from the photographs, the Bear sports an amtrac-like appearance and employs a dual flexible-track system for traversing difficult terrain. Each track is equipped with its own suspension system.

The Bear is constructed in three major parts. The lower chassis contains the robot's propulsion, suspension, and electrical power systems. The upper chassis houses all computer and electronic processing equipment, including user-interface devices. The sensor turret, which can be rotated 45 degrees in each direction, and the lasers are used to detect distant obstacles.

The Actron Bear perceives its environment through forty-two chassis-mounted and eight turret-mounted ultrasonic sensors. The turret sensor array can be rotated to sweep the environment and acquire information on obstacles located up to 32 feet away.

AcroTek suggests the following uses for the Bear:

- Rescue downed policemen or soldiers
- Help police suppress a violent riot
- Act as decoy for manned vehicles
- Move heavy suspected bombs
- Deliver supplies under fire
- Patrol the country’s borders
- Rescue aliens in trouble
- Patrol perimeter fence line
- Patrol oil and gas pipelines

The Bear operates on diesel fuel, has a maximum speed of 15 miles per hour (mph), and a range of up to 50 miles. It weighs about 1,800 pounds and has a payload of approximately 1,200 pounds.

BigDog

System Name: BigDog

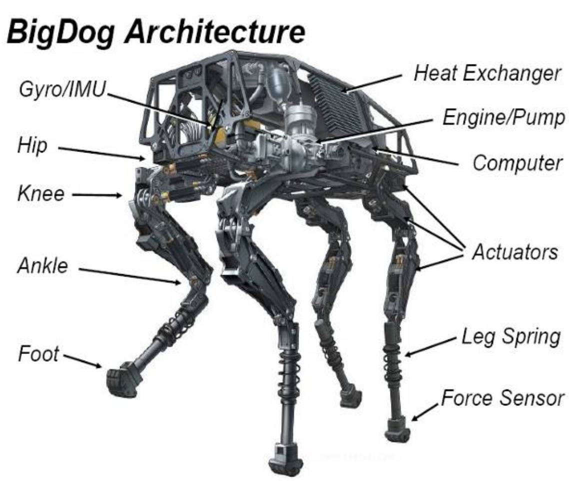
Manufacturer: Boston Dynamics

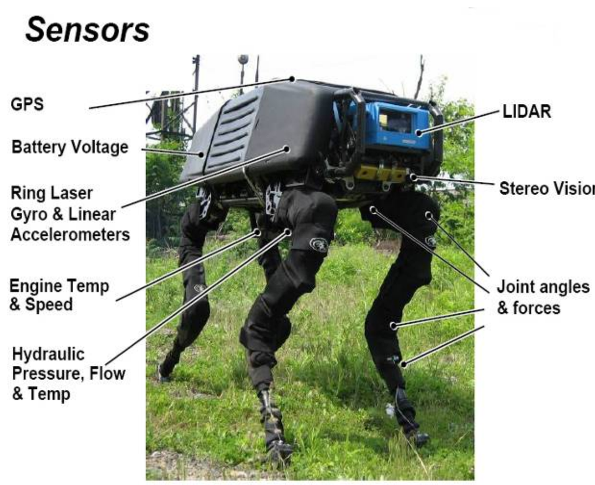
Country: U.S.A**.**

Rank: 11/15

Score: 27/55 Points







Strengths: Autonomy

Weaknesses: Mission Duration; Communications

Website: http://www.bostondynamics.com/robot_bigdog.html

General Discussion: Big Dog

BigDog is probably the "Rock Star" of unmanned systems; Boston Dynamics (of Waltham, Massachusetts) refers to BigDog as "the alpha male of the Boston Dynamics robots." Who hasn't seen at least one video on YouTube of BigDog doing its thing?

BigDog is a rough-terrain robot that walks, runs, climbs and can carry a load; in their response to SSC Pacific, Boston Dynamics put the payload at 300 pounds on flat terrain and 120 pounds on a trail. This is impressive given that the gross weight of BigDog is 240 pounds.

The size of a large dog or small mule, BigDog is about 3 feet long and 2.5 feet tall. It is powered by a small engine (a Leopard one-cylinder, two-stroke, water-cooled go-cart engine) that develops about 15 horsepower and drives a hydraulic actuation system. BigDog has four legs that are articulated like an animal's, with compliant elements to absorb shock and recycle energy from one step to the next.

BigDog's strong suit involves both autonomy and movement. Its on-board computer controls locomotion, servos the legs and handles a variety of sensors. Its control system keeps it balanced, navigates, and regulates its energetics as conditions vary. Sensors for locomotion include joint position, joint force, ground contact, ground load, a gyroscope, Lidar and a stereo vision system. Other sensors focus on the internal state of BigDog, monitoring the hydraulic pressure, oil temperature, engine functions, battery charge, and other functions.

BigDog Sensors

Type	Measurement Quantity	Location	N	
Linear Pot	Joint displacements	Knee, Hip (2), Ankle	16	
Load Cell Current Sensor	Actuator, ankle force Servo valve current	Legs eBox	16 16	Proprioception
Stereo Vision	Obstacles, Optic Flow Ground Slope	Body	3	
LIDAR	Human Tracking	Body	1	
Gyro	3 angular rates 3 linear accelerations	Body	6	Exteroception
Temperature	Engine, Oil temperature	Body	3	
Flow	Oil flow	Body	4	
Pressure	Oil pressure	Body	2	Homeostasis
Governor	Engine RPM Battery voltage	Body	2	
Total			69	

At this point in its development, BigDog is not particularly speedy; it runs at 2.5 – 4 mph (although it has achieved 7 mph briefly). It climbs slopes up to 35 degrees, walks across rubble, climbs a muddy hiking trail, walks in snow and water, and carries up to a 300-pound load. BigDog set a world record for legged vehicles by traveling 12.8 miles without stopping or refueling.

According to Boston Dynamics, the ultimate goal is to develop BigDog (or successor) into a robot that can go anywhere people and animals can go. The program is funded by the Tactical Technology Office at DARPA. The follow-on DARPA project is called the Legged Squad Support System and is described in the DARPA Broad Agency Announcement (BAA) 08-71 dated 24 October 2008.

R-Gator

System Name: Robotic Gator ("R-Gator")

Manufacturer: iRobot / John Deere

Country: U.S.A.

Rank: 12/15

Score: 27/55 Points

Strengths: Range; Payload; Recoverability

Weaknesses: Mission Duration; Communications; Mobility (Vertical Obstacle and Ditch Traversal); Transportability (Weight = 2,242 pounds)

Website: http://www.deere.com/en_US/contractsales/fedmilitarysales/cce/r_gator/r_gator.html

General Discussion: R-Gator

Back in October of 2004, John Deere (founded in 1837; headquartered in Moline, Illinois) and iRobot (founded in 1990; headquartered in Bedford, Massachusetts) unveiled the Military Robotic Gator, or “R-Gator.” The R-Gator is based on the John Deere M-Gator, a rugged, reliable utility vehicle that deployed with the first units to see action in the opening days of Operation Enduring Freedom. Thousands of M-Gators have now been delivered to military units all over the world and are in extensive use in both Iraq and Afghanistan.

The R-Gator is a remotely-driven version of the 6x6 M-Gator vehicle. The R-Gator is fitted with robotic control unit modules, together with an inertial navigation system (INS)/GPS system. With a curb weight of 1,450 pounds, the R-Gator can haul or tow up to 1,400 pounds, including passengers and cargo.

The R-Gator can be operated autonomously, teleoperated, or manually driven as a normal M-Gator (it has seats for two passengers), with the ability to shift quickly between teleoperated, autonomous and manual modes. In autonomous mode, R-Gator uses numerous sensors to detect obstacles and guide the vehicle. With the flip of a switch, the operator can transition to manual mode and drive the vehicle like a car. The vehicle automatically collects a series of waypoints while it is manually driven or tele-operated, enabling it to retrace its path autonomously.

With its 3-cylinder, 18-horsepower diesel engine, the R-Gator’s top speed is 5 mph in autonomous and tele-operated mode, and 18 mph in manual mode. With a 5.3 U.S. gallon fuel tank, the R-Gator has a range of approximately 300 miles (according to a John Deere brochure) or 8 hours (according to a John Deere / iRobot brochure), depending on terrain and conditions.

According to the manufacturer, missions for which R-Gator might be suited include the following:

- unmanned reconnaissance (both on- and off-road)
- perimeter patrols
- surveillance and inspection of dangerous or sensitive areas such as pipelines
- shuttling supplies automatically from rear supply points to forward operating positions
- following in warfighters’ footsteps, carrying heavy backpacks, ammunition, and supplies

MDARS

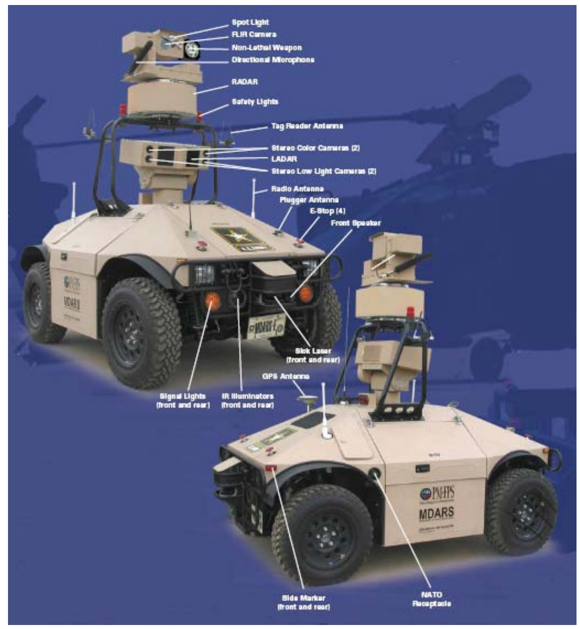
System Name: Mobile Detection Assessment Response System (MDARS)

Manufacturer: General Dynamics Robotic Systems

Country: U.S.A.

Rank: 13/15

Score: 26/55 Points



Strengths: Range

Weaknesses: Mission Duration; Mobility (Vertical Obstacle and Ditch Traversal); Transportability (Weight = 3,500 pounds)

Website: http://www.gdrs.com/robotics/programs/program.asp?UniqueID=27

General Discussion: MDARS

MDARS is a program of the Army's Joint Program Executive Office for Chemical and Biological Defense (JPEO-CBD) – Product Manager, Force Protection Systems (PM-FPS), developed by General Dynamics Robotic Systems (GDRS), Westminster, Maryland. General Dynamics Robotic Systems has been developing the MDARS concept since 1993.

The robot is designed to perform random patrols around Department of Defense warehouses, airfields, ammunition supply depots, and port facilities – i.e., security missions at structured/semi-structured facilities. MDARS semi-autonomously conducts surveillance activities including checking for intruders, remotely investigating alarm sources, monitoring high-value inventory, and assessing facility barriers, such as the doors of storage bunkers. As currently configured, the system requires the pre-installation of route segments on an *a priori* map.

MDARS is a diesel-powered four-wheel hydrostatic-drive vehicle with a payload capacity of 500 pounds. The vehicle is equipped with a real-time obstacle avoidance system and 360-degree sensors. It can operate for 16 hours without refueling and at speeds up to 20 miles per hour.

Early User Appraisal (EUA) activities for MDARS have been ongoing at the Hawthorne Army Depot in Hawthorne, Nevada since August 2004 and the system has been in limited use by the civilian operator guard force at the Depot since October 2004. The MDARS demonstration vehicles have logged more than 8,000 hours and 28,000 miles of service since 2005. Subsequently, in early 2008, the U.S. Army awarded General Dynamics Robotic Systems an indefinite delivery/indefinite quantity (IDIQ) contract with a total potential value of $40 million for production of the MDARS system.

According to the manufacturer, some of MDARS features include the following:

- Autonomous, random patrol missions or can be remotely operated by joystick
- Attains speeds of up to 20 mph / can operate for 16 hours without refueling
- Detects intruders at 200 meters
- Detects breached security locks
- Monitors radio-frequency (RF)-tagged inventory
- Control station allows the operator to manage up to 16 MDARS vehicles simultaneously
- Equipped with real-time obstacle-avoidance systems and 360-degree sensors
- Distributed control system

As can be seen in the photographs above, the MDARS platform, at approximately 8.5 feet, is quite tall – in fact, it is too tall to fit into the V-22 with the upper sensor package attached. Although the sensor bracket (and the associated radar, forward-looking infrared (FLIR) camera, directional microphone, tag reader antenna, non-lethal weapon mount, lights, etc.) can be removed, the MDARS system was never designed to have this section removed other than for repair/replacement. It is a difficult, time-consuming, and sensitive process. In other words, it is not something that could or should be routinely undertaken, particularly in an austere, expeditionary environment. In addition, the current system does not feature an unrestricted path planner that can deviate from pre-planned route segments, as would be required in tactical missions.

Hero

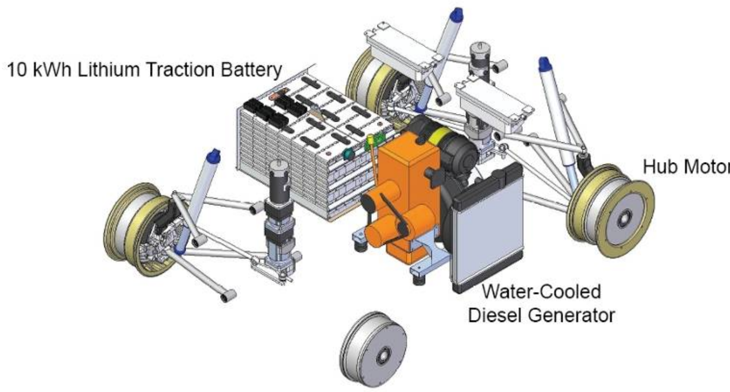
System Name: Hero

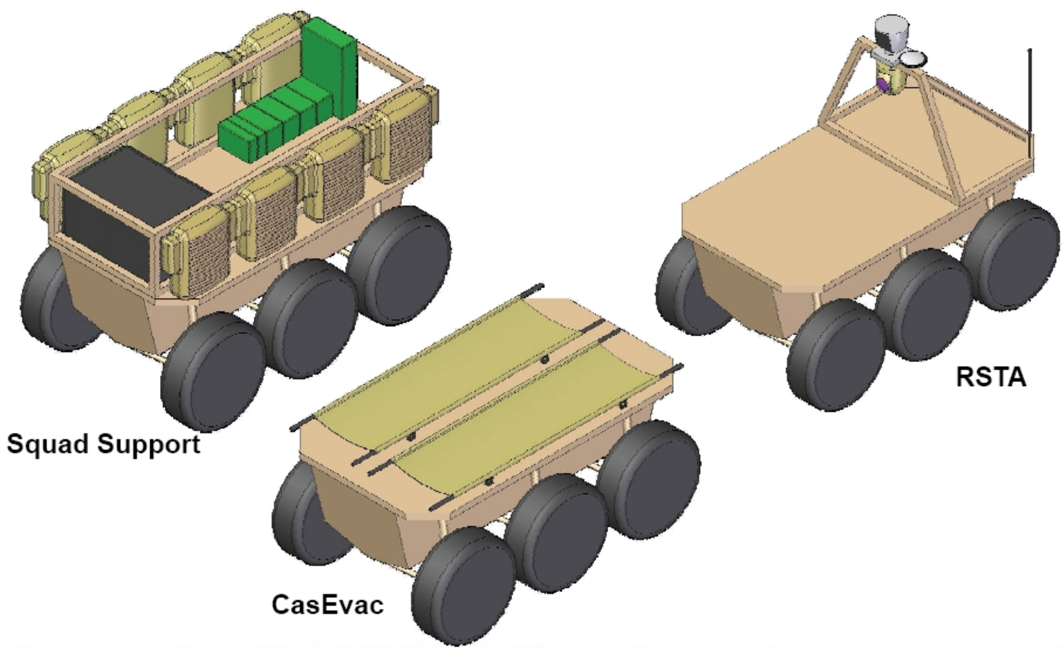
Manufacturer: Radiance Technologies, Inc.

Country: U.S.A.

Rank: 4/15

Score: 25/55 Points





Strengths: Range; Speed

Weaknesses: Mission Duration; Mobility (Vertical Obstacle and Ditch Traversal); Transportability (1,300 pounds (Hero 1.0) / 2,000 pounds (Hero 2.0))

Website: http://www.auburn.edu/research/vpr/sri/nationalsecurity.htm

General Discussion: Hero

Radiance Technologies, Inc., located in Huntsville, Alabama, has been developing the “Hero” line of UGVs for the Air Force Research Laboratory (AFRL) Automated Perimeter Security project. The photograph and exploded-view graphic shown on the preceding page are of the Hero 1.0; the six-wheeled variant shown in the lower graphic are of the Hero 2.0, in development.

A distinctive element of the Hero is that it is a diesel-electric hybrid, intended to give operators the ability to conduct various unmanned missions with little risk of aural detection. While a diesel prime power unit allows JP-8 logistics fuel capability, a high-capacity lightweight battery provides persistent Silent Watch capabilities. Hub motors, independent suspension, and steering at all four corners allow maneuverability, traction, and control.

Single power-source systems have well-known drawbacks. Diesel-only solutions tend to be loud; on the other hand, battery-only solutions tend to have very limited range and endurance. Silent operation duration is dominated by battery capacity, which tends to be reduced in adverse temperatures. Furthermore, batteries can be difficult and time consuming to exchange, and rechargeable solutions require charging equipment and a power source.

Hybrid Systems permit intermittent silent operation with longer run-times for the same weight as battery-only systems. Refueling generally takes very little time and the hybrid can interoperate with existing logistic fuel infrastructure.

The Hero 1.0 sports hub motors at all four wheels, coupled with four-wheel steering (The Hero 2.0 will offer six-wheel drive and the same six-foot turning radius as the four-wheeled Hero 1.0). The flat upper deck permits a payload of 200 pounds (increased to 1,000 pounds with the Hero 2.0). The Hero 2.0 will also be faster (with a 75 mph vs. 29 mph “Sprint Speed”), but – like the Hero 1.0 – will still be internally transportable within the CH-46 and V-22 Osprey roll-on/roll-off envelope.

In terms of autonomous capability, the current system development is focused on force protection and surveillance roles and supports waypoint navigation with simple obstacle avoidance in addition to tele-operation. The system also supports a remotely-operated weapons system (ROWS) solution, using Radiance Technologies’ own “WeaponWatch” unit (http://www.radiancetech.com/products/weaponwatch.htm).

SilverBack

System Name: SilverBack

Manufacturer: Codarra Advanced Systems Pty Ltd.

Country: Australia

Rank: 15/15

Score: 25/55 Points

Strengths: Range; Speed

Weaknesses: Mission Duration; Mobility (Vertical Obstacle and Ditch Traversal); Transportability (Weight = 500 pounds)

Website: http://www.codarra.com.au/products/silverback.jsp

General Discussion: SilverBack

Codarra Advanced Systems is an Australian company, established in Canberra in 1989, specializing in consulting services, systems integration, project management, and training.

Codarra is developing the Silverback UGV as a remote-control reconnaissance vehicle. With a gross vehicle weight of 500 pounds, the Silverback can manage a payload of 220 pounds. The Silverback has a 150cc air-cooled engine and a range of approximately 100 miles (and, according to Codarra, a 16-hour endurance, with the option to increase range and loiter capability by installing additional fuel tanks). Its maximum speed is 28 mph.

The Silverback possesses a video surveillance and audio communications capability that combine with its manipulator arm. Its development path currently includes a laser range-finder, deployable sensor devices, motion detectors, and high-assurance weapon control systems, although it has the flexibility to include user-defined technologies.

An all-terrain remote-control reconnaissance vehicle, the Silverback has been designed principally for the military, police, and emergency services. In addition to the developmental systems mentioned above, it is capable of carrying a wide variety of integrated payloads and surveillance technologies.

Although it is currently a teleoperated system, Codarra plans to develop autonomous capabilities for the Silverback, including object identification, visual mapping, path planning, and “swarming” operation with other vehicles. In terms of testing, the manufacturer states that it has performed successfully in demonstrator trials and is undergoing feature enhancements and testing with state-of-the-art payload technologies. The Silverback can be purchased in standard form or can be customized with mission-specific payloads and capabilities.

SECTION V. SUMMARY, CONCLUSION, AND RECOMMENDATIONS

SUMMARY

In this market survey, we researched and reviewed over 500 unmanned ground systems from around the globe, which we later winnowed down to a “mere” 436. In the course of this research, we sent follow-up RFIs regarding over 200 of the more promising systems, receiving responses for approximately 65 of these. We conducted in-depth open-source research, aggregation, and data fusion to acquire baseline information on hundreds of additional systems.

As our research progressed, three caveats quickly became apparent. First, it was not possible to acquire the exhaustive information that we sought for every extant UGV. Although SSC Pacific assembled a large and motivated team to seek out and classify the target UGV platforms, it would be presumptuous to suggest that no system was overlooked. We are well aware that new systems are constantly being introduced, even as older systems are being retired.

Second, even among the hundreds of systems that were identified, we were not able to gain a full complement of information for each and every system. Many companies simply failed to respond to our requests for information, no doubt for a variety of reasons. However, we can hypothesize that, in many cases, the companies that self-selected out of our research probably did so believing that their respective systems simply did not meet the criteria stipulated by ONR.

Finally, we must acknowledge that much of the data that were collected came directly from the manufacturers. Consequently, these data without question contain substantial marketing hyperbole and an exaggerated opinion of the various systems’ capabilities. This is both natural and to be expected.

However, even as we acknowledge these caveats, it seems clear that limitations such as these are inherent in virtually any market survey. Furthermore, it was apparent from the outset of our research that no existing system would fully possess the suite of capabilities addressed in the ONR SOW. As a result, our goal was not to identify the best COTS system available today for SUMET, but rather to provide an accurate overview of both the state-of-the-practice and the trajectory of the technologies and capabilities that are of interest to the SUMET program.

Utilizing a somewhat relaxed scoring system based on a subset of the ONR criteria, SSC Pacific reviewed each and every system in the collected database, placing them into one of three categories: Red (for failing one or more of the key criteria); Green (for provisionally meeting each of the criteria), or Yellow (insufficient information at this point to pass or fail).

With respect to the “Yellow” systems, these represented systems for which we had been seeking information, although – in general – with rather limited success. At this point in our research, we focused on these systems and followed up with additional research, including Internet and telephone inquiries. As a result, we were able to reclassify many of these systems as either “Red” or “Green.” Nonetheless, time constraints did not permit an open-ended program of research, and many of our “Yellow” systems belong to companies which never acknowledged or responded to our contact efforts.

Finally, it was necessary to score the “Green” systems and rank-order them, according to a more complete list of performance criteria (see Table 4). Three SSC Pacific engineers independently reviewed and scored all of the “Green” systems. Where the total score for a given system varied by

more than three points between any pair of raters, that system was jointly discussed and reviewed again by all three raters until scoring consensus was achieved. The top 15 systems are profiled and discussed in Section IV.

CONCLUSION

Who makes the best unmanned ground vehicle? According to the research and analysis protocol we have described, the "best" UGV appears to be the Chrysor by Robowatch Technologies GmbH of Germany. Besides the caveats mentioned above, however, note that the Chrysor scored just 35 out of 55 points possible, or about 64%. Even among the top systems, none comes anywhere near "acing" the performance criteria and each of them possesses significant weaknesses among one or more of the criteria. In fact, among the systems reviewed, no single system is "best-of-breed" across the board for all – or even most – of the performance criteria.

Perhaps it is not surprising that the SUMET performance criteria are not especially well met in the current and emerging crop of UGVs; this can be attributed to at least two independent factors. First, it is quite clear that the lion's share of attention, effort, and money over the past few years have gone towards addressing and mitigating the IED threat. If we had rated unmanned systems based on ability to deal with IEDs, I'm sure we would have seen very different scoring profiles. In fact, we should anticipate different scoring profiles for virtually every possible mission (or application area) from the slate of existing UGVs.

Second, it was very clear from the outset that the technology capabilities that ONR had specified for SUMET – including both the "Minimum Performance" and "Desired Performance" capabilities described in the SOW and reflected in Table 1 – set the bar very high. So high, in fact, that no system in the world is able to achieve high marks in each of the eight independent technology capability categories.

To reiterate, our goal in the present market survey was not to name names and pronounce the winner in the "SUMET Search for the Best COTS UGV." Instead, we have sought to highlight the state-of-the-practice and trajectory of the technologies that are of interest to ONR with respect to SUMET.

With this in mind, we turn next to a series of recommendations for the SUMET program.

RECOMMENDATIONS

In selecting, designing, or specifying requirements for a SUMET-mission capable UGV, a number of key capabilities and requirements must be kept in mind (Everett, 1985).

- **Autonomy –** Clearly, a central component of the SUMET mission involves a high level of autonomous functionality, both to free warfighters from tedious low-level concerns and to ensure that warfighters maintain critical situation awareness of the tactical environment. Elements of autonomous functionality include:
  - **Collision Avoidance –** Requires both sophisticated sensors (hardware) and algorithms (software) to permit the UGVs to acquire the necessary three dimensional (3D) information about the environment and process it rapidly.
  - **Navigational Planning –** The SUMET UGV must be capable of determining its precise location in order to maneuver effectively to the desired position, while circumventing obstructions and hazards and avoiding detection. Additionally, the system must be capable of calculating the optimum path to its destination, taking the forgoing constraints into consideration – a task which is computationally intensive.

- **Computational Resources –** While Moore's Law[10] promises regularly increasing computational capabilities, "more" is never enough and improved hardware and software will be essential to meeting the challenges of massive amounts of data, endless calculations, and the symbolic reasoning necessary to emulate the required degree of intelligence for even the most primitive of systems.
- **Application-Specific Sensors and Controls –** Alluded to above, the SUMET UGV will require an appropriate sensor suite and associated intelligence in order to perform the mission(s) that it is assigned.
- **Motion Effectors –** As observed in the course of the current market study, there are many ways for a UGV to move about, including tracks, wheels, and legs. Additional research will be required to further develop effective and efficient motion effectors for optimal maneuverability, dexterity, traction, etc., in light of SUMET's UGV mission(s).
- **Energy Sources –** It quickly became clear in the course of the present market survey that power sources remain a difficult and important consideration for UGVs, with very different capabilities in terms of travel distance, refueling/recharging, etc.
- **Human-System Interface –** The HSI (or "man-machine interface") is one of the most important, but frequently overlooked, aspects of any complex man-machine system. While the SUMET UGV must operate as autonomously as possible (in order to minimize human cognitive burden and distraction), some interaction is inevitable and research should be planned to ensure that the SUMET UGV "interfaces" well with its Marine infantry unit.
- **Training and Self-Diagnostics –** The importance of this area cannot be overemphasized. While the SUMET UGV will reflect substantial improvements in mobility, speed, power, utility, and a variety of other capabilities, these easily could be offset by problems associated with operator training, system integration, and maintenance and repair. It may never be practical to provide the requisite skill levels needed through conventional means, including contractor training, MOS schools, etc. Even if theoretically possible, such training would be expensive and, as we have often observed among the technical MOSs, we can expect to lose many of our highly-trained personnel to better paying jobs in industry. Therefore, the SUMET UGV must be fully proficient in diagnosing its own problems and self-correcting to the extent possible.

As discussed previously, even among the most capable UGVs reviewed in this market study, none "aces" the performance criteria and each system demonstrates weaknesses among one or more of the criteria. Among the systems reviewed, no single system is "best-of-breed" across the board for all (or even most) of the performance criteria. This observation is not unique to the SUMET requirements; in fact, it is quite unlikely that any given manufacturer will possess the best-of-breed in terms of platform hardware, sensors, computational resources, mobility and autonomy algorithms, etc.

Realizing this inevitability many years ago, SSC Pacific has established a network of relationships with a wide variety of organizations in government, industry, and academia, each the recognized leader in its field. By leveraging truly "best-of-breed" components (both hardware and software), it is possible to develop unmanned systems for virtually any application while minimizing the deficiencies and shortcuts inherent in most commercial offerings. Furthermore, with years of experience in this high-level system integration role, SSC Pacific has become expert at creating and

[10] "Moore's Law" is the observation, made in 1965 by Intel co-founder Gordon Moore while preparing a speech, that each new memory integrated circuit contained roughly twice as much capacity as its predecessor, and each chip was released within 18-24 months of the previous chip. If this trend continued, he reasoned, computing power would rise exponentially with time. This prediction has held for over four decades. (Source: Dictionary.com, http://dictionary.reference.com/browse/moore's%20law)

developing the necessary “middleware” to permit each of the components to perform and interact optimally.

A few final recommendations would seem to be in order. As ONR continues to identify and refine the operating capabilities and characteristics required for SUMET, we suggest that the information presented in the present market study be utilized to:

(1) Invite selected manufacturers for operational test and evaluation of existing systems;

(2) Issue Requests for Proposal (RFPs) with an iteratively refined set of required technology capabilities; and

(3) Commission SSC Pacific, or another organization with similar capabilities, to act as both honest broker and as systems integrator, creating one or more prototype systems using best-of-breed hardware and software components.

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APPENDIX A – ACRONYMS

3D...Three Dimensional

Acer..Armored Combat Engineer Robot

AFRL ....Air Force Research Laboratory

AO..Area of Operations

AP ....Anti-Personnel

Archer ....Advanced Remote-Controlled Hybrid Experimental Robot

AT ....Anti-Tank

ATV ....All-Terrain Vehicle

AUVSI ....Association for Unmanned Vehicle Systems International

BAA ....Broad Agency Announcement

BEAR..Battlefield Extraction-Assist Robot

CBRNE ....Chemical, Biological, Radiological, Nuclear, and high-yield Explosives

cc..Cubic Centimeter

COTS ....Commercial Off-The-Shelf

DARPA...Defense Advanced Research Projects Agency

DHS..Department of Homeland Security

DOF..Degrees of Freedom

DTI...Defense Technologies, Inc.

EFSS ....Expeditionary Fire Support System

EOD ....Explosive Ordnance Disposal

EUA ....Early User Appraisal

FLIR..Forward-Looking Infrared

GDRK ....GDRS Robotics Kit

GDRS..General Dynamics Robotics Systems

GmbH..Gesellschaft mit beschränkter Haftung (literally, “Company with Limited Liability”)

GPS ....Global Positioning System

GWOT..Global War on Terror

HMMWV or Humvee ....High Mobility Multipurpose Wheeled Vehicles

HSI ....Human-System Interface

IAI ....Israel Aerospace Industries

IDIQ ....Indefinite Delivery / Indefinite Quantity

IED...Improvised Explosive Device

INS ....Inertial Navigation System

ITV...Internally-Transportable Vehicle

JGRE..Joint Ground Robotics Enterprise

JPEO-CBD...Joint Program Executive Office for Chemical and Biological Defense

Kg...Kilograms (1,000 grams, or about 2.2 lbs)

km/h or kph..Kilometers per Hour (about .621 mph)

LADAR...Laser Radar

LASER..Light Amplification by the Stimulated Emission of Radiation

LBE..Load-Bearing Equipment

LC ....Limited Company

LIDAR ....Light Detection and Ranging

LLC..Limited Liability Company

LMTV ....Light Medium Tactical Vehicle

LS3...Legged Squad Support System (DARPA Program)

m ....Meter (about 39.37 inches)

MARCORSYSCOM..........................Marine Corps Systems Command

MCWL ....Marine Corps Warfighting Laboratory

MDARS ....Mobile Detection, Assessment, and Response System

mph ....Miles Per Hour

NATO ....North Atlantic Treaty Organization

NBC ....Nuclear, Biological and Chemical

NIST..National Institute of Standards and Technology

OCU ....Operator's Control Unit

OEF ....Operation Enduring Freedom

OIF ....Operation Iraqi Freedom

ONR ....Office of Naval Research

PM-FPS...Product Manager, Force Protection Systems

PPE..Personal Protective Equipment

Pty Ltd...Proprietary Limited

RADAR...Radio Detection and Ranging

RF..Radio Frequency

RFI ....Request for Information

RFP ....Request for Proposal

R-Gator ....Robotic Gator

RMP ....Robotic Mobility Platform

ROWS ....Remotely-Operated Weapons System

RTO...Research and Technology Organization (NATO)

SA ....Situation Awareness

SOF ....Special Operations Forces

SOW..Statement of Work

SPAWAR..Space and Naval Warfare

SSC ....SPAWAR Systems Center

SUMET ....Small Unit Mobility Enhancement Technologies

UGV..Unmanned Ground Vehicle

URBEE ....Urban Environment Exploration

APPENDIX B – MARKET SURVEY RFI FORM

Unmanned Ground Vehicle (UGV)
Market Survey

A. Organizational Information		
A.1	System Name	
A.2	Manufacturer	
A.3	Address	
A.4	System Website	
A.5	POC / Program Manager	
A.6	Telephone	
A.7	E-Mail	

B. System Physical Data		
B.1	Gross Vehicle Weight (pounds)	
B.2	Payload Weight (pounds)	
B.3	Size (Length) (Feet/Inches)	
B.4	Size (Width)	
B.5	Size (Height) (w/payload)	
B.6	Power / Fuel Required	
B.7	If System is Battery Operated, Indicate: * Type of Battery (is it a proprietary battery or is it a standard military battery?) * Battery Life (Hours/Mins) * Battery Rechargeability	
B.8	Rough order of magnitude (ROM) Cost	
B.9	Projected Full Scale Production Cost	
B.10	Ground Clearance (feet / inches)	
B.11	Operating Temperatures (ºC / ºF)	

C. System Autonomy Capabilities		
C.1	Is the System purely tele-operated (i.e., no semi-autonomous control)? (Yes/No)	
C.2	Basic Autonomy: Is the system able to “follow the leader” in line-of-sight operations as part of a Marine infantry fire team? If so, please describe.	
C.3	Advanced Autonomy: Is the system able to meet, follow, etc. dismounted Marines without increasing the mental or physical workload of the Marines? If so, please describe.	
C.4	Describe more fully the autonomous capabilities of the system.	

D. System Mobility		
D.1	What is the Vehicle Range (Miles) (Without Refueling or Recharging)?	
D.2	What is the maximum Mission Duration (Hours)? For example, in observation mode, how long can it “sit & stare?”	
D.3	Does the system have wheels, tracks, legs, or some other means of mobility? Please describe	
D.4	What type of steering does the system employ (ackerman, differential, etc.)?	
D.5	What is the maximum grade the system can traverse?	
D.7	Can the system detect and avoid “positive obstacles” (e.g., debris)? If so, at what maximum speed?	
D.6	Can the system detect and avoid “negative obstacles” (e.g., ditches)? If so, at what maximum speed?	
D.8	Is the system able to traverse urban and non-mountainous desert roads, surmounting debris greater than 12 inches in height and crossing ditches greater than 3 feet in width, at dismounted Marine running speed (i.e., about 6 mph)? Please describe which capabilities the system possesses, and to what degree.	

D.9	Is the system able to cover ≥95% of the terrain that a Marine is able to cover (while wearing individual equipment), including fording rivers, climbing through windows, navigating in caves, climbing over urban rubble and boulder fields, etc. at running speed (i.e., about 6 mph)? Please describe which capabilities the system possesses, and to what degree.	
D.10	What is the system Maximum Speed (mph)?	
D.11	Recoverability (Mechanical): Does the system have a winch attachment for recovery?	
D.12	Recoverability (Manual): Is the system shaped in such a way with lift points that two (2) Marines can lift and carry it a short distance (10m)? Note that, according to MIL-STD-1472F, one male can lift and carry for 10m an object of up to 82 pounds.	
D.13	Recoverability (Manual): Is the system shaped in such a way with lift points that four (4) Marines can lift and carry it a short distance (10m)? Note that, according to MIL-STD-1472F, one male can lift and carry for 10m an object of up to 82 pounds.	

E. System Sensors / Modularity		
E.1	Standard Sensors: Which sensors are “standard” with the system?	
E.2	Additional Sensors: Which additional sensors are available or optional with the system?	
E.3	Please describe the degree of modularity (i.e., “plug-and-play” capabilities) of the system, including * Sensors * Drive system * Power (batteries / fuel cells) etc.	

F. Command and Control		
F.1	Radio Communications: Please indicate number and type(s) of radios; range(s); and data rate(s)	
F.2	Communications Capabilities: indicate the ability of the system to communicate with dismounted Marines using a wearable computer (or similar device) for command and control, data entry, etc.	
F.3	Advanced Communications Capabilities: Please indicate the ability of the system (if any) to respond to a variety of Marine communications, including words, whistles, hand-and-arm signals, beacons, etc.	
F.4	Transportability: Can the Unmanned System be transported via MV-22 Osprey (Yes/No)? (Note that the cargo bay of an MV-22 Osprey can accommodate an internal payload up to 20,000 pounds; the interior cargo dimensions are: 66” (H) x 68” (W) x 24’ (L). Additionally, the Osprey can accommodate an external cargo load up to 15,000 pounds.)	
F.5	Is the system JAUS Compatible? If “Yes,” which version of JAUS?	
F.6	Is the system software “Open Architecture?” If yes, please describe.	
F.7	Is a license required? (If so, indicate cost of license.)	

G. Operational Readiness		
G.1	Technology Readiness Level: Please indicate the TRL of this system.	
G.2	Military Ruggedness Testing: Has the system undergone Military Standard Ruggedness Testing (e.g., MIL-STD-810E / F)? Please indicate the nature and results of the testing, if any. (Note: MIL-STD-810E/F establishes uniform environmental test methods for determining the resistance of equipment to the effects of natural and induced environments peculiar to military operations.)	
G.3	Operational Experience: Please provide examples of Current Usage of this system (e.g., Programs of Record)	
G.4	Safety Release: Has the system been granted a Safety Release? If so, for what purpose (e.g., operation or experiment) and for what time frame?	

APPENDIX C – DATABASE EXTRACT OF UGVS REVIEWED

The following systems were reviewed as part of the present market survey and assessment.

Please note that the "System Website" column generally provides links addressing the specific platform and not the manufacture/vendor site in general.

Country	System Name	Manufacturer	System Website
Australia	Beagle	Ausrobot	http://www.ausrobot.com/products.php?product=BEAGLE
Australia	Digger	BAE Systems Australia	www.baesystems.com/australia
Australia	Echidna EOD Robot	DOWNER EDI LIMITED	http://www.downeredi.com
Australia	Ferret	Ausrobot	http://www.ausrobot.com/products.php?product=FERRET
Australia	Inspecta	Ausrobot	http://www.ausrobot.com/products.php?product=INSPECTA
Australia	RASP	DSTO	http://www.dsto.defence.gov.au
Australia	Sentry	Ausrobot	http://www.ausrobot.com/products.php?product=SENTRY
Australia	SilverBack	Codarra Advanced Systems Pty Ltd	http://www.codarra.com.au/products/silverback.jsp
Australia	Spiker	Ausrobot	http://www.ausrobot.com/products.php?product=SPIKER
Australia	Spiker	DSTO	http://www.dsto.defence.gov.au
Australia	X-MUTS	DSTO	http://www.dsto.defence.gov.au
Austria	Crayler BM Portable Forklift	PALFINGER CRAYLER STAPLERTECHNIK GMBH	www.palfinger.com
Austria	FMR 2000 Large tracked mineclearing UGV	HADI Maschinenbau	www.hadi.at
Austria	PALFINGER CRAYLER FLG 140	PALFINGER Europe GmbH	www.palfinger.com
Cambodia	Tempest	Development Technology Workshop	www.dtw.org.kh
Canada	Badger	Meggitt Training Systems	http://www.meggitttrainingsystems.com/
Canada	Bombtec Defender	Allen Vanguard	http://www.allen-vanguard.com/

Country	System Name	Manufacturer	System Website
Canada	Extreme Machine	Victory Systems, LLC and Trillamation/Weldmation	not found
Canada	Grunt	Frontline Robotics	http://www.frontline-robotics.com
Canada	Jacobs Rugg Robot	Inuktun	www.inuktun.com
Canada	Micro Variable Geometry Tracked Vehicle (VGTV)	Inuktun	www.inuktun.com
Canada	MIL Remote Control Demining Vehicle	MILITARY INTERNATIONAL LIMITED	http://www.milcanada.com
Canada	MK 1 Caliber Scout Robot	ICOR TECHNOLOGY	WWW.ICORTECHNOLOGY.COM
Canada	MK 2 Caliber Tactical Robot	ICOR TECHNOLOGY	WWW.ICORTECHNOLOGY.COM
Canada	MK3-CALIBER® EOD Robot	ICOR Technology Inc.	www.icortechnology.com
Canada	MR-5	Engineering Services Inc	www.esit.com
Canada	MR-7	Engineering Services Inc	www.esit.com
Canada	MR-D	Engineering Services Inc	www.esit.com
Canada	Nano Mag	Inuktun	www.inuktun.com
Canada	Proximiter	Rotoconcept Robotics Inc.	http://rotoconcept.com/projects/projects.htm
Canada	RMI-10F	Pedsco, Ontario	http://www.pedsco.com/contact.php
Canada	RMI-9WT	Pedsco	http://www.pedsco.com/contact.php
Canada	ROC ENABLED AUGV (Autonomous Unmanned Ground Vehicle) Based on Polaris Defense MVRS vehicle	Frontline Robotics Inc	http://www.frontline-robotics.com/
Canada	Sect 2	Applied Ai Systems	http://www.AAI.ca
Canada	Vanguard ROV	Allen Vanguard	http://www.allen-vanguard.com/
Canada	Variable Geometry Tracked Vehicle (VGTV) Xtreme	Inuktun	www.inuktun.com
Canada	Versatrax 100	Inuktun	www.inuktun.com

Country	System Name	Manufacturer	System Website
Canada	Versatrax 150	Inuktun	www.inuktun.com
Canada	Versatrax 300	Inuktun	www.inuktun.com
Canada	VGTV	Inuktun	www.inuktun.com
Canada	VGTV-Extreme	Inuktun	www.inuktun.com
Croatia	Grizzly-1	DOK-ING, Zagreb	www.dok-ing.hr
Croatia	Jelka 4 Medium Class Multipurpose Firefighting Vehicle	DOK-ING	http://dok-ing.hr/
Croatia	Mine Sweeper RM-KA-02.	Duro Dakovic Specijalna Vozila, Slavonski Brod	http://www.dd-elektromont.com
Croatia	MV 10	DOK-ING	www.dok-ing.hr
Croatia	MV 4 Mini Flail	DOK-ING	www.dok-ing.hr
Croatia	MV-20	DOK-ING	www.dok-ing.hr
Croatia	MVD mini dozer.	DOK-ING, Zagreb	www.dok-ing.hr
Finland	Patria RA-140 DS	Patria	www.patria.fi
France	AMX-30B/B2 DT	NEXTER Systems	www.nexter-group.fr
France	Brokk & Samm	Cybernetix	www.cybernetix.fr
France	Cameleon	ECA	www.eca.fr
France	Castor	Cybernetix (ECA)	www.cybernetix.fr
France	Castor	ECA	www.eca.fr
France	Cayman	ECA	www.eca.fr
France	CITV-1 buggy	Survey-Copter	www.survey-copter.com
France	CLOME-1	Survey-Copter	www.survey-copter.com
France	CMAG-1	Survey-Copter	www.survey-copter.com
France	Cobra	Cybernetix	www.cybernetix.fr
France	Cobra M.R.	ECA	www.eca.fr
France	EBENNE	Groupe Intra	http://www.groupe-intra.com
France	EBULL	Groupe Intra	http://www.groupe-intra.com
France	EOLE	Groupe Intra	http://www.groupe-intra.com

Country	System Name	Manufacturer	System Website
France	EPELL	Groupe Intra	http://www.groupe-intra.com
France	ERASE	Groupe Intra	http://www.groupe-intra.com
France	ERELT	Groupe Intra	http://www.groupe-intra.com
France	Eros	Groupe Intra	http://www.groupe-intra.com
France	Eros	Cybernetix	www.cybernetix.fr
France	Inbot	ECA	www.eca.fr
France	LMF/Menhir	Cybernetix	www.cybernetix.fr
France	Magic Atol	Thales	www.thalesgroup.com
France	MRS	ECA	www.eca.fr
France	PRM	ECA	www.eca.fr
France	RM 35	Cybernetix	www.cybernetix.fr
France	RM135	ECA	www.eca.fr
France	Robson	Exavision	www.exavision.com
France	robuCAR TT	Robosoft	www.robosoft.fr
France	robuROC4	Robosoft	www.robosoft.fr
France	robuROC6	Robosoft	www.robosoft.fr
France	Syrano	NEXTER Systems	www.nexter-group.fr
France	TSR 202	ECA	www.eca.fr
France	TSR-200	Cybernetix	www.cybernetix.fr
France	VERI II B	Groupe Intra	http://www.groupe-intra.com
France	Vigiland	Cybernetix	www.cybernetix.fr
France	WifiBot 4G	Robosoft	www.robosoft.fr
Germany	AKW-E	KAPPA Opto-electronics GmbH	http://www.kappa.de
Germany	ASENDRO	Robowatch & Diehl BGT Defence	www.robowatch.de
Germany	ASENDRO EOD	Robowatch & Diehl BGT Defence	www.robowatch.de
Germany	ASENDRO EOD(not available at the moment)	Robowatch Technologies GmbH	http://www.robowatch.dehttp://www.robowatch.de/index.php?id=141 http://www.robowatch.de/index.php?id=143

Country	System Name	Manufacturer	System Website
Germany	ASENDRO Scout	Robowatch & Diehl BGT Defence	www.robowatch.de
Germany	AUG-V8	Robowatch Technologies	www.robowatch.de
Germany	Chrysor	Robowatch Technologies GmbH	http://www.robowatch.dehttp://www.robowatch.de/index.php?id=303
Germany	COBOLD	Diehl Bgt Defence	www.diehl-bgt-defence.de
Germany	Firerob	Telerob	http://www.telerob.com
Germany	Foxbot	Rheinmetall Defence Electronics	http://www.rheinmetall-defence.com
Germany	Guideline: Robotic Convoy	Jacobs University	www.jacobs-university.de
Germany	Knight	ForceWare	www.forceware.de
Germany	KURT II	KTO	http://ivs.cs.uni-magdeburg.de/EuK/forschung/labor/cora/corad.shtml
Germany	MEL 940	Meltron	http://www.meltron.com
Germany	MEL 950	Meltron	http://www.meltron.com
Germany	MG-400	Neobotix	http://www.neobotix.de
Germany	Minebreaker 2000/2	FFG Flensburger Fahrzeugbau	www.ffg-flensburg.de
Germany	MM-500	Neobotix	http://www.neobotix.de
Germany	MOSRO	Robowatch Technologies GmbH	http://www.robowatch.dehttp://www.robowatch.de/index.php?id=121
Germany	MOSRO	Robowatch Technolgoies	www.robowatch.de
Germany	MP-L655	Neobotix	http://www.neobotix.de
Germany	MP-M470	Neobotix	http://www.neobotix.de
Germany	MP-S500	Neobotix	http://www.neobotix.de
Germany	OFRO	Robowatch	www.robowatch.de
Germany	OFRO+Detect	Robowatch	www.robowatch.de
Germany	OFROOFRO + detect	Robowatch Technologies GmbH	http://www.robowatch.dehttp://www.robowatch.de/index.php?id=130 http://www.robowatch.de/index.php?id=137
Germany	Primus	EADS	http://www.eads.net

Country	System Name	Manufacturer	System Website
Germany	Rhino	Rheinmetall Landsysteme	http://www.rheinmetall-defence.com
Germany	Robbie 6	Univercity Koblenz - Landau	www.uni-koblenz-landau.de/forschung/fona/stiftungen
Germany	Roboscout	Base 10	www.btse.de
Germany	Robotec	SIM	www.sim.tu-darmstadt.de/edu/rob1/robrefs.html
Germany	Robotec 2	SIM	www.sim.tu-darmstadt.de/edu/rob1/robrefs.html
Germany	Safety Guard	Telerob	http://www.telerob.com
Germany	SON	KAPPA Opto-electronics GmbH	http://www.kappa.de
Germany	teleMax	Telerob	http://www.telerob.com
Germany	TeleMax. Medium tracked explosive ordnance disposal (EOD) UGV.	Telerob, Ostfildern.	www.telerob.de
Germany	tEODor 13	Telerob	http://www.telerob.com
Germany	tEODor 23	Telerob	http://www.telerob.com
Germany	Trobot	Rheinmetall Landsysteme	http://www.rheinmetall-defence.com
Germany	VMN 2000 Wasp	VET GmbH Demining Technology	not found
Germany	Wiesel 2 Digital	Rheinmetall Landsysteme	http://www.rheinmetall-defence.com
Greece	Aris	Soukos Robotic	http://soukosrobots.gr
Greece	Hercules Mini	Soukos Robotic	http://soukosrobots.gr
Greece	Hercules Mk1	Soukos Robotic	http://soukosrobots.gr
Greece	Hercules Mk2	Soukos Robotic	http://soukosrobots.gr
Greece	IOV 225	HTR	http://www.htr.gr/index.htm
Greece	Iraklis	Soukos Robotic	http://soukosrobots.gr
Greece	Minotaur		http://soukosrobots.gr
Greece	Odysseas	Soukos Robotic	http://soukosrobots.gr
Greece	Polifimos	Soukos Robotic	http://soukosrobots.gr

Country	System Name	Manufacturer	System Website
Greece	QU 1120	HTR	http://www.htr.gr/index.htm
Iran	Taftan 1 Mine Cleaner	Defence Industries Organisation, Armour Industries Group	http://www.diomil.ir
Israel	TSR-650 Wasp	Israel Military Industries	http://www.imi-israel.com
Israel	AvantGuard	Elbit Systems	http://www.elbitsystems-us.com/
Israel	Avidor-2004	Elbit Systems	wWw.odfopt.com
Israel	Beagle	Elbit Systems	http://www.elbitsystems.com
Israel	D9	InRob Tech	http://www.inrobtech.com
Israel	Eye Drive	ODF Optronics	wWw.odfopt.com
Israel	Eyeball	ODF Optronics	wWw.odfopt.com
Israel	FFR-1	InRob Tech	http://www.inrobtech.com
Israel	Front Runner	InRob Tech	http://www.inrobtech.com
Israel	Guardium	G-NIUS	www.g-nius.co.il
Israel	Hornet MK1	Israel Military Industries	http://www.imi-israel.com
Israel	Hornet MK5	InRob Tech	http://www.inrobtech.com
Israel	Light Robotic Tracked Vehicle (LRTV)	Technion, Israel Institute of Technology, Land Systems R & D Division	www.robotics.technion.ac.il
Israel	REX – Infantry Robotic Porter	IAI - Israel Aerospace Industries Ltd	www.iai.co.il
Israel	TSR-700	Israel Military Industries	http://www.imi-israel.com
Israel	VIPeR	Elbit Systems	http://www.elbitsystems.com
Israel	Guardium UGV. Large wheeled patrol UGV.	G-NIUS, Tel Aviv.	http://www.g-nius.co.il/
Italy	Anser	Genova Robot	www.genovarobot.com
Italy	Eco-Robot Robot family		not found
Italy	Eco-Robot Robot family	Eco-Robot	not found
Italy	Eco-Robot Robot family	Eco-Robot	not found
Italy	Oto TRP 2	Oto Melara	http://www.otomelara.it

Country	System Name	Manufacturer	System Website
Italy	Praetor	Oto Melara	http://www.otomelara.it
Italy	Super Desert Runner	Elettronica Melara	http://www.elettronicamelara.it
Japan	6WD	Sakakibara-Kikai	www.sakakibara-kikai.co.jp
Japan	All-Purpose Remote Transport System (ARTS)	Tohoku University	www.tohoku.ac.jp/english/
Japan	Cphea	Toin University of Yokohama	http://www.cc.toin.ac.jp/univ/english
Japan	Hibiscus	Chiba Institute of Technology	www.it-chiba.ac.jp/english/
Japan	Hitachi-Furukawa	Furukawa	www.furukawa.co.jp/english/index.htm
Japan	Iris	Chiba Institute of Technology	www.it-chiba.ac.jp/english/
Japan	MineBull	Kawasaki Heavy Industries	http://www.khi.co.jp
Japan	MineDog	Kawasaki Heavy Industries	http://www.khi.co.jp
Japan	NuTech-R4.1	Nagaoka University of Technology 1603-1 Kamitomioka, Nagaoka, Niigata, Japan, ZIP:940-2188	Tetsuya KIMURA
Japan	(Various)	Hirose Fukushima Robotics Lab	http://www-robot.mes.titech.ac.jp/robot_e.html
Jordan	KADDB. Medium wheeled armed and hazardous duty UGV	King Abdullah II Design and Development Bureau	www.kaddb.com
Jordan	Three Versions:Lynx-C Combat RobotLynx-E IED/EOD RobotLynx-J RF-Jamming Robot	Jordan Electronic Logistics Support (JELS)	www.jels-tech.com
Namibia	CamTrack	HEC (Hendrik Ehlers Consult)	http://www.ehlersconsult.com/index.htm
Namibia	MgM Rotar MK-II	Menschen gegen Minen e.V. MgM	www.mgm.org
Namibia	Wer'wolf MKII MPV	Windhoeker Maschienfabrik (WMF)	http://www.wmf.com.na/wer_wolf_mk_ii.aspx

Country	System Name	Manufacturer	System Website
Netherlands	Cheatah Mobility Base Frame Platform VTE-3500. Medium tracked multipurpose UGV	Parosha Innovators B.V., Lemoenappel	http://www.cheatah-tugv.com/?pag_id=34911&site_id=202
Netherlands	HD-1J	IRS	www.is.northropgrumman.com/by_solution/.../index.html
Netherlands	Modular Log. Platform	IRS	not found
Norway	Armored Mine Clearing Vehicle	ALVIS MOELV AS	http://www.alvismoelv.no
Norway	Blaster	Steinsvik Maskinindustri (?)	http://www.nortechinc.com/html/steinsvik.html
Norway	Compact 140 Minemouse	Norwegian Demining Consortium	http://www.nodeco-me.com/
Norway	Compact 230 Minecat	Norwegian Demining Consortium	http://www.nodeco-me.com/
Norway	MineCat 140 KE	Aver Kvaerner Eureka	http://www.akersolutions.com/Ext/Eureka/ProductsAndServices/Mine+Clearing+Systems/MineCat+140+KE/Default.htm
Norway	MineCat 230 KE	Aver Kvaerner Eureka	http://www.akersolutions.com/Ext/Eureka/ProductsAndServices/Mine+Clearing+Systems/MineCat+230+KE/Default.htm
Norway	Viking Mine Clearing System (VMCS)	Alvis Moelv AS	http://www.alvismoelv.no http://www.baesystems.com/Businesses/LandArmaments/Divisions/GlobalCombatSystems/BAESystemsAB/Divisions/Hagglunds/ProductsServices/index.htm
Poland	Ibis (Poland) Large wheeled explosive ordnance disposal (EOD), improved explosive device disposal (IEDD) and armed UGV	PIAP, Warsaw	http://www.antiterrorism.eu/
Poland	Inspector	PIAP	http://www.antiterrorism.eu/
Poland	Scout	PIAP	http://www.antiterrorism.eu/
Poland	Surveillance Robot SR 100-Expert	PIAP	http://www.antiterrorism.eu/
Poland	Talos	PIAP	www.piap.pl

Country	System Name	Manufacturer	System Website
Portugal	Raposa. Small tracked reconnaissance UGV	IdMind - Engenharia de Sistemas Lisbonl	http://raposa.idmind.pt/?l=en
Russia	Varan	Kovrov Electro-Mechanic Plant	http://www.kemz.org/IndexEn.html
Russia	Vezdekhod TM-3	Kovrov Electro-Mechanic Plant	http://www.kemz.org/IndexEn.html
Russia (Denmark?)	Mine Area Clearance Equipment (MACE)	Hydrema Joint Stock Co.	http://www.hydrema.com/
Slovakia	Bozena 4/5 (Slovakia)	Way Industry	www.way-industry.sk
Slovakia	Diana 44T Large tracked flail mineclearing UGV	Hontstav S.R.O , Krupina	www.hontstav.com
Slovakia	Retriever Small wheeled reconnaissance UGV	Kerametal, Bratislava	www.kerametal.sk/en
Slovakia	Scorpio Small tracked under-vehicle inspection and reconnaissance UGV	Kerametal, Bratislava	www.kerametal.sk/en
Slovenia	Minemill MC 2004	Trademill Mejac	http://www.demining.si/t4/index.php?id=22
Slovenia	Samson	Vilpo	http://www.vilpo.si/index.php?option=com_frontpage&Itemid=1&lang=english
South Africa	Casspir MPV with VAMIDS	Mechem	http://www.mechemdemining.com/
South Korea	Athena	DoDaam Systems	http://dodaam.com/home_en/product/c4i/combat%20ugv%20athena.html
South Korea	Platform	Dasa Tech	http://genibo.dasarobot.com/english/
South Korea	PRP	Robot & Design (?)	not found
South Korea	Robhaz 6W	Robhaz	www.robhaz.com
South Korea	Robhaz DT	Robhaz	www.robhaz.com
South Korea	Robhaz DT2	Robhaz	www.robhaz.com
South Korea	Robhaz DT3	Robhaz	www.robhaz.com
South Korea	Robot Guard	Robot & Design (?)	not found

Country	System Name	Manufacturer	System Website
Spain	Guardian Robot. Wheeled medium reconnaissance and explosives defeating UGV.	Robotnik Automation, Valencia	http://www.robotnik.es/automation/robotnik-e.php
Spain	Rescuer. Large tracked multipurpose UGV	Robotnik Automation, Valencia	http://www.robotnik.es/automation/robotnik-e.php
Sweden	Bofors Defence Mine Guzzler	Bofors Defence AB	not found
Sweden	Bofors Mine Breaching Vehicle	SAAB BOFORS DYNAMICS AB	http://www.saabgroup.com
Sweden	Brokk 180	Brokk	http://www.brokk.com/
Sweden	Brokk 330	Brokk	http://www.brokk.com/
Sweden	Brokk 40	Brokk	http://www.brokk.com/
Sweden	Brokk 50	Brokk	http://www.brokk.com/
Sweden	Brokk 90	Brokk	http://www.brokk.com/
Sweden	GroundBot	ROTUNDUS	http://www.rotundus.se/
Sweden	Mine Guzzler. Large tracked mineclearing UGV	Originally produced by Bofors AB, now produced by Rybro International Limited , Salisbury	not found
Sweden	Oracle	Countermine Engineering AB	http://www.countermine.com/en/services/oracle.html
Sweden	Scanjack 3500	ScanJack	www.scanjack.com
Switzerland	Digger 1	Digger Demining Technologies Research	http://www.digger.ch/home/
Switzerland	Digger D-2	Digger DTR	http://www.digger.ch/home/
Switzerland	MineWolf	MINEWOLF SYSTEMS	http://www.minewolf.com/
Switzerland	Mini MineWolf	MINEWOLF SYSTEMS	http://www.minewolf.com/
Switzerland	Shrimp III	Bluebotics	http://www.bluebotics.com/
Switzerland	Spybot	MACROSWISS	www.macroswiss.com (website inaccessible) http://www.armedforces-int.com/categories/spy-robots/macroswiss-presents-new-improved-spyrobot-4wd.asp
Switzerland	MineWolf	Minewolf Systems	www.minewolf.com

Country	System Name	Manufacturer	System Website
Switzerland	Mini MineWolf	Minewolf Systems	www.minewolf.com
Turkey	Gezgin Medium tracked reconnaissance and armed UGV	Aselsan, Ankara	http://www.aselsan.com.tr/
Turkey	Izci. Medium wheeled reconnaissance and patrol UGV.	Aselsan, Ankara, Turkey	http://www.aselsan.com.tr/
Turkey	T-Robot	Kompozitek , Ankara	http://kompozitek.com
UK	Aardvark Mini-flail	AARDVARK CLEAR MINE	www.landmineclearance.com
UK	Aardvark MK IV	Aardvark Clear Mine Ltd (?)	www.landmineclearance.com
UK	Armtrac 100	Armtrac	http://www.armtrac.net/armtrac100.php
UK	Armtrac 25	Armtrac	not found
UK	Armtrac 325	Armtrac	not found
UK	Armtrac 400	Armtrac	http://www.armtrac.net/armtrac75.php
UK	Armtrac 75	Armtrac	http://www.armtrac.net/armtrac75.php
UK	Armtrac 75t	Armtrac	http://www.armtrac.net/armtrac75.php
UK	Assault Breacher Vehicle (ABV)	Pearson Engineering	http://www.pearson-eng.com/
UK	Bison	AB Precision	http://www.abprecision.co.uk/
UK	Bomb Responsive Anti Terrorist (BRAT) Vehicle	PW ALLEN & COMPANY	not found
UK	Buckeye	AB Precision	http://www.abprecision.co.uk/
UK	Cheatah VTE-3500 TUGV	King Metaal	www.kingmetaal.nl
UK	Cutlass. Medium wheeled explosive ordnance disposal (EOD) UGV.	Remotec, Coventry	www.remotec.co.uk
UK	Cyclops (Mk 4D). Small tracked or wheeled improvised explosive device disposal (IEDD) and reconnaissance	AB Precision (Poole)	http://www.abprecision.co.uk/

Country	System Name	Manufacturer	System Website
	UGV		
UK	Cyclops Mk 4C	AB Precision	http://www.abprecision.co.uk/
UK	Decomissioning Robot	Smith Engineering	not found
UK	Defender ROV	ALLEN-VANGUARD	http://www.allenvanguard.com/ViewProduct.aspx?ProductId=491&CategoryId=169
UK	Groundhog	Qinetiq	not found
UK	Guardian	AB Precision	http://www.abprecision.co.uk/
UK	Hero. Small wheeled under-vehicle inspection UGV	BAE Systems, Warton, UK	www.baesystems.com
UK	Hobo L3A1	ALLEN-VANGUARD	not found
UK	Imp	ALLEN-VANGUARD	not found
UK	JCB170 FireFighting	Qinetiq	not found
UK	Longcross	Qinetiq	http://www.qinetiq.com/home/defence/defence_solutions/landjo/robotic_platforms0/longcross_robot.html
UK	Lynx	AB Precision	http://www.abprecision.co.uk/
UK	MACE	MIRA	www.mira.co.uk
UK	Mine-Guzzler	Rybro International	www.rybro.co.uk
UK	Mini MoonBuggy	Smith Engineering / MoonBuggy	http://www.moonbuggy.com/Mini%20Moonbuggy%20ugv.pdf
UK	Moon Buggy (Diesel)	Smith Engineering / MoonBuggy	http://www.moonbuggy.com/Moonbuggy%20diesel%20ugv.pdf
UK	Moon Buggy (Petrol)	Smith Engineering / MoonBuggy	http://www.moonbuggy.com/Moonbuggy%20petrol%20ugv.pdf
UK	Moon Buggy EOD	Smith Engineering / MoonBuggy	http://www.moonbuggy.com/Moonbuggy%20petrol%20ugv.pdf
UK	New WheelBarrow	Qinetiq	not found
UK	Rangemaster RCV	Qinetiq	http://www.qinetiq.com/home/defence/defence_solutions/landjo/robotic_platforms0/other_robots.html
UK	Redbus Bigfoot	Redbus LMDS	http://www.redbus.co.uk
UK	Redbus LMDS	Redbus LMDS Ltd.	http://www.redbus.co.uk

Country	System Name	Manufacturer	System Website
UK	Redbus MineWorm	Redbus LMDS	http://www.redbus.co.uk
UK	Revolution. Medium tracked chemical, radioactive, biological, nuclear and explosive (CBRNE) UGV.	Remotec UK, Coventry.	http://www.remotec.co.uk/pdf/MK8%20Plus%20II.pdf
UK	ROID	Oxford Technologies	http://www.oxfordtechnologies.co.uk
UK	ROID 102	Oxford Technologies	http://www.oxfordtechnologies.co.uk
UK	Super M Remote EOD Vehicle(s)	REMOTEC UK	http://www.remotec.co.uk/pdf/MK8%20Plus%20II.pdf
UK	Super M. Medium tracked explosive ordnance disposal (EOD) UGV	Remotec UK, Coventry	http://www.remotec.co.uk/pdf/MK8%20Plus%20II.pdf
UK	Testudo. Small wheeled reconnaissance UGV	Mindsheet, Havant	www.mindsheet.com
UK	Vanguard ROV	ALLEN-VANGUARD	http://www.allenvanguard.com/ViewProduct.aspx?ProductId=503&CategoryId=169
UK	Wheelbarrow MK 8 Plus II	REMOTEC UK	http://www.remotec.co.uk/pdf/MK8%20Plus%20II.pdf
UK	Wheelbarrow Revolution	REMOTEC UK	http://www.remotec.co.uk/pdf/Revolution.pdf
USA	Acer	Mesa Robotics	www.mesa-robotics.com
USA	ACME Robot	ACME Products	not found
USA	Actron Badger	Acrotek, Inc	www.acrotek.com
USA	Actron Bear	Acrotek, Inc	www.acrotek.com
USA	Actron Wolf	Acrotek, Inc	www.acrotek.com
USA	Andros HD-1 Medium tracked multipurpose UGV.	Remotec Inc	www.northropgrumman.com
USA	Andros Mk V-A1 Hazardous Duty Mobile	Remotec Inc	www.northropgrumman.com
USA	Andros Wolverine	Remotec Inc	www.northropgrumman.com

Country	System Name	Manufacturer	System Website
USA	ARCH (Autonomous Remote Control HMMWV)	TORC	www.torctech.com
USA	ARCHER / Archer BATTLEWAGON	Elbit Systems of America	http://www.elbitsystems-us.com
USA	Archer-V Hybrid	Reflexx Robotics	http://reflexxrobotics.com/products/platforms/archer
USA	ARES	Applied Perception	http://www.appliedperception.com/products-ares.htm
USA	Armadillo Demining Machine	PLOUGHSHARE TECHNOLOGIES (TERRA SEGURA INTERNATIONAL)	www.terrasegura.org - denied access
USA	Armed Robotic Vehicle	BAE SYSTEMS GROUND SYSTEMS DIVISION	www.baesystems.com
USA	ART 1	Angelus Research Corporation	http://www.angelusresearch.com/art.htm
USA	ART/ATO Vehicle	General Dynamics Robotic System	http://www.gdrs.com/robotics/programs/program.asp?UniqueID=4
USA	ARTS - RC 50 Large tracked mineclearing and explosive ordnance disposal (EOD) UGV.	Wesco Manufacturing	www.wescomfginc.com
USA	ATRV mini	iRobot	www.irobot.com
USA	AUNAV	Proytecsa AUNAV	http://bozrobot.com/
USA	Aurora Small tracked reconnaissance and hazardous duty UGV.	Automatika, Pittsburgh, Pennsylvania.	not found
USA	Autonomous Rhino Ground Vehicle (ARGV)	Brock Technologies, Inc.	http://www.brocktechnologies.com/WebPages/Unmanned Ground Vehicles/ARGV/ARGV.htm
USA	Badger Multimission Law Enforcement Robot	Interactive Target Systems, Jackson, Michigan.	http://www.interactivetarget.com
USA	BARCS - Basic Remoted Controlled System	www.lockheedmartin.com	www.lockheedmartin.com

Country	System Name	Manufacturer	System Website
USA	Bear Medium, tracked multipurpose UGV.	Vecna Robotics	www.vecna.com
USA	BigDog	Boston Dynamics	http://www.BostonDynamics.com/robot_bigdog.html
USA	Black Knight. Large tracked combat UGV.	BAE Systems Ground Systems, Arlington, Virginia.	www.baesystems.com
USA	BomBot	Innovative Response Technologies	www.irt-robotics.com
USA	BomBot2	Innovative Response Technologies	www.irt-robotics.com
USA	Bowler Wildcat	BAE Systems	www.baesystems.com
USA	Boz1 Boz XL	Boz Robotics	www.segway.com
USA	BROKK (Also labeled as "KOBRA" Products)	AMEASOL-BROKK	www.brokkinc.com and www.ameasol.com
USA	CBRN Unmanned Ground Reconnaissance (CUGR)	EDGEWOOD CHEMICAL BIOLOGICAL CENTER	www.edgewood.army.mil
USA	Chaos. Medium tracked reconnaissance and logistics UGV	Autonomous Solutions, Petersboro, Utah	www.autonomoussolutions.com
USA	Cobra Tactical Robot System	Simulator Systems, Robotics Division	http://www.simulatorsystems.com/index.htm
USA	COPPERHEAD	Simulator Systems, Robotics Division	http://www.simulatorsystems.com/index.htm
USA	COUGAR Tactical Support Robot	Cubic	not found
USA	Crusher. Large wheeled combat UGV.	Carnegie Mellon University, Pittsburgh, Pennsylvania	http://www.frc.ri.cmu.edu/projects/terrascout/index.html
USA	Cyclops. Small ball reconnaissance UGV.	Automatika, Pittsburgh, Pennsylvania	not found
USA	Demo III	General Dynamics Robotic System	not found

Country	System Name	Manufacturer	System Website
USA	Dismounted Operations: TAC-C	General Dynamics Robotic System	not found
USA	Dragon Runner SUGV	Associated Research Association	http://www.automatika.com/products-dr15.htm
USA	Dragon Runner SUGV	QinetiQ North America	www.dragonrunner.com
USA	EFSS	American Growler, Inc	http://www.capitaldefense.com/AmericanGrowler.shtml
USA	Elbit Beagle SUGV	Elbit Systems of America	http://www.elbitsystems-us.com
USA	Elbit VIPeR SUGV	Elbit Systems of America	http://www.elbitsystems-us.com
USA	Element	Mesa Robotics	www.mesa-robotics.com
USA	Escape	GDRS (TORC)	not found
USA	ExplorBot	Openware Robotics	www.alibaba.com/product/parrisht-10845009.../Explorbot.html
USA	Extreme Machine	Victory Systems, LLC and Trillamation/Weldmation	not found
USA	ForkBot	Jackson and Tull (formerly OAO Robotics), Washington, District of Columbia.	www.jacksonandtull.com
USA	FTA Riverbot Concept	Fast Track Amphibian LLC	www.fasttrackamphibian.com
USA	G2Bot	Mesa Robotics	www.mesa-robotics.com
USA	Georgia Tech Sting 1 UGV	Georgia Tech	http://www.cc.gatech.edu/projects/sting-racing http://www.gtri.gatech.edu/casestudy/urban-challenge-run-ends
USA	Gladiator Large wheeled multipurpose UGV	Carnegie Mellon University, Pittsburgh, Pennsylvania	www.cmu.edu
USA	Griffon Hybrid UAV/UGV	iRobot	www.irobot.com
USA	HDE Robotics Group TR-2000 robot system	HDE Robotics Group, Inc.	www.Hdemfg.com
USA	HERO	First Response Robotics	http://www.firstresponserobotics.com
USA	HERO / HERO 2.0	Radiance Technologies, Inc	http://www.auburn.edu/research/vpr/sri/nationalsecurity.htm

Country	System Name	Manufacturer	System Website
USA	Humvee Part of GDRK & CAMS	GDRS	not found
USA	Ibis TEK Lightweight Robotics Weapon Platform	Ibis TEK LLC , Butler, Pennsylvania	www.ibistek.com
USA	INBOT. Small wheeled reconnaissance UGV.	Simulator Systems, Robotics Division	http://www.simulatorsystems.com/index.htm
USA	Intruder	Angelus Research Corporation	http://www.angelusresearch.com/intruder.htm
USA	iRobot Negotiator. Small tracked reconnaissance UGV	iRobot, Burlington, Massachusetts	www.irobot.com
USA	iRobot PackBot® 510 Advanced EOD	iRobot Corporation	http://www.irobot.com http://www.irobot.com/sp.cfm?pageid=325
USA	iRobot PackBot® 510 Engineer	iRobot Corporation	http://www.irobot.com http://www.irobot.com/sp.cfm?pageid=325
USA	iRobot PackBot® 510 EOD	iRobot Corporation	http://www.irobot.com http://www.irobot.com/sp.cfm?pageid=325
USA	iRobot PackBot® 510 First Responder	iRobot Corporation	http://www.irobot.com http://www.irobot.com/sp.cfm?pageid=325
USA	iRobot PackBot® 510 with Enhanced Fas Tac	iRobot Corporation	http://www.irobot.com http://www.irobot.com/sp.cfm?pageid=325
USA	iRobot PackBot® 510 with Fas Tac	iRobot Corporation	http://www.irobot.com http://www.irobot.com/sp.cfm?pageid=325
USA	iRobot PackBot® 510 with HazMat	iRobot Corporation	http://www.irobot.com http://www.irobot.com/sp.cfm?pageid=325
USA	iRobot Warrior™ 700	iRobot Corporation	http://www.irobot.com http://www.irobot.com/sp.cfm?pageid=150
USA	Jaguar	Autonomous Solutions	www.autonomoussolutions.com

Country	System Name	Manufacturer	System Website
USA	Knight Medium wheeled or tracked explosives defeating and hazardous duty UGV.	WM Robots, Colmar, Pennsylvania.	www.wmrobots.com
USA	Landshark E	Black I Robotics	http://blackirobotics.com/Home_Page.html
USA	Lector HD Small tracked reconnaissance UGV	Tactical Systems, Gilbert, Arizona	http://tacticalrobots.com/
USA	Lector NR Small tracked reconnaissance UGV	Tactical Systems, Gilbert, Arizona	http://tacticalrobots.com/
USA	Lector split chassis tactical robot Small wheeled reconnaissance UGV	Tactical Systems, Gilbert, Arizona	http://tacticalrobots.com/
USA	Light Forces Anti-Personnel Mine Mini-Flail	Marion Metal Works, Ocala, Florida	www.marionmetalworks.com
USA	M5-A Scout Medium wheeled hazardous duty and surveillance UGV	Kraft TeleRobotics, Overland Park, Kan	krafttelerobotics.com/
USA	MAARS Modular Advanced Armed Robotic System	Foster-Miller/QinetiQ North America, Waltham, Massachusetts.	www.foster-miller.com/
USA	Mad Robot (Target UGV)	United Service Associates , Van Nuys, California	www.usasmog.com/
USA	MARCbot Small wheeled explosives defeating UGV	Exponent, Inc.	http://www.exponent.com/marcbot_product/
USA	Marv. Small tracked multipurpose UGV.	Mesa Robotics, Madison, Wisconsin.	www.robotics.me.wisc.edu
USA	Matilda	Mesa Robotics	www.mesa-robotics.com
USA	Mini Andros II	Remotec Inc	www.northropgrumman.com

Country	System Name	Manufacturer	System Website
USA	Mini Flail	Columbia Research Corporation	www.columbiagroup.com
USA	MK3-CALIBER® EOD Robot	ICOR Technology Inc.	www.icortechnology.com
USA	MoATV	BAE Systems	www.baesystems.com
USA	Mobile Detection Assessment and Response System (MDARS)	General Dynamics Robotic Systems	http://www.gdrs.com
USA	MOLE - Material and Ordnance locator and Eliminator	AUTAUGA ARMS	not found
USA	MPR-150. Medium tracked multipurpose UGV.	OAO Corporation (Now Lockheed Martin)	www.lockheedmartin.com
USA	MUGV	Northrop Grumman - Remotec	http://www.ms.northropgrumman.com/Remotec/index.htm
USA	MULE Large wheeled multipurpose UGV. There are three variants - transport (MULE-T), Armed Robotic Vehicle - Assault (Light) (MULE ARV-A (L)) and countermine (MULE-C).	Lockheed Martin Missiles and Fire Control Systems, Orlando, Florida.	http://www.lockheedmartin.com/products/mule/index.html
USA	MURV - 100	HDE	www.Hdemfg.com
USA	MURV - 100 -S	HDE Manufacturing, Fort Worth, Texas.	www.Hdemfg.com
USA	MURV-22 Robot System	HDE Manufacturing, Fort Worth, Texas.	www.Hdemfg.com
USA	NABCO TATV-01 Tracked TCV Transporter	NABCO, Canonsburg, Pennsylvania.	www.nabcoinc.com
USA	Navigator	Applied Perception	not found
USA	Neptune	Automatika & Carnegie Mellon	not found
USA	PackBot Explorer	iRobot Corporation	www.irobot.com

Country	System Name	Manufacturer	System Website
USA	Pandora. Small tracked reconnaissance UGV	Automatika, Pittsburgh, Pennsylvania.	not found
USA	Pointman. Small wheeled reconnaissance UGV	Applied Research Associates, Inc	http://www.ara.com/products/LRV_Brochure.pdf
USA	Porter	Vecna Technologies, Inc.	http://vecnarobotics.com/solutions/porter.shtml
USA	PYTHON	Simulator Systems, Robotics Division	http://www.simulatorsystems.com/index.htm
USA	R500e Robot	SAIC	http://www.saic.com/products/robot-r500e/
USA	Rabbit 11B Robot Counter IED System (RCIS)	BAE Systems	www.baesystems.com
USA	Ranger Modular Robot	Angelus Research Corporation	http://www.angelusresearch.com/military/RangerRobotBrochure.pdf
USA	RANLO	Defense Technologies	www.dtiweb.net
USA	Recon Scout IR. Small wheeled under-vehicle inspection and reconnaissance UGV.	Recon Robotics	www.reconrobotics.com
USA	Reconnaissance Robotic Vehicle (R2V)	Global Technical System (GTS)	http://www.gtshp.com/
USA	RECORM Robot. Small wheeled reconnaissance and explosives defeating UGV.	JACKSON AND TULL (FORMERLY OAO ROBOTICS)	not found
USA	Remote All-Terrain System (RATS)	Jackson and Tull (formerly OAO Robotics), Washington, District of Columbia.	not found
USA	R-Gator Large wheeled logistics and patrol UGV.	iRobot, Burlington, Massachusetts.	http://www.irobot.com

Country	System Name	Manufacturer	System Website
USA	Rhex	Boston Dynamics	http://www.bostondynamics.com/robot_rhex.html
USA	Ripsaw MS1/MS2. Large tracked armed UGV	Howe and Howe Technologies, Eliot, Maine	www.howeandhowe.com
USA	RiSE	Boston Dynamics	http://www.bostondynamics.com/robot_rise.html
USA	River Patrol UGV/USV	Fast Track Amphibian LLC	www.fasttrackamphibian.com
USA	RMP 200 ATV	Segway	www.segway.com
USA	RMP 400	Segway	www.segway.com
USA	Robotic Combat Casualty Extraction and Evacuation	Applied Perception	not found
USA	Robotic Mobility Platform	Remotec Inc	www.remotec.northropgrumman.com/
USA	RPR	Applied Perception	not found
USA	Scorpion	Mesa Robotics	www.mesa-robotics.com
USA	Scorpion Autonomous Vehicle - Chrome	Preferred Chassis Fabrication Inc.	www.scorpion4x4.com or www.preferredchassis.com
USA	Seeker series R500 Robot. Small wheeled reconnaissance and explosives defeating UGV.	AMTI, an operation of SAIC, Arlington, Virginia.	www.amti.com
USA	Seekur. Medium wheeled patrol and logistics UGV.	MobileRobots, Amherst, New Hampshire	www.mobilerobots.com
USA	Sidewinder Small and rugged, tactical explosive ordnance disposal (EOD) UGV.	Simulator Systems, Robotics Division	http://www.simulatorsystems.com/index.htm
USA	Small Flail	Columbia Resaerch Corporation	www.columbiagroup.com
USA	Small Unmanned Ground Vehicle (SUGV) 300 series (310 and 320)	iRobot	http://irobot.com/sp.cfm?pageid=219

Country	System Name	Manufacturer	System Website
USA	Soryu	Autonomous Solutions	www.autonomoussolutions.com
USA	Soryu V	Autonomous Solutions	www.autonomoussolutions.com
USA	Spector. Small wheeled under-vehicle inspection UGV	Autonomous Solutions, Petersboro, Utah	www.autonomoussolutions.com
USA	Spidar. Small wheeled reconnaissance UGV.	Automatika, Pittsburgh, Pennsylvania.	not found
USA	Spinner	Autonomous Solutions	www.autonomoussolutions.com
USA	Squad Mission Support System (SMSS)	Lockheed Martin Missiles and Fire Control	www.LockheedMartin.com
USA	Sting UGV	Georgia Institute of Technology Robotics and Intelligent Machines	www.sting-racing.org www.robotics.gatech.edu
USA	Stryker Part of GDRK & CAMS	GDRS	not found
USA	SUGV	iRobot Corporation	www.irobot.com
USA	Super AUNAV	Proytecsa AUNAV	http://www.proytecsa.es/
USA	Super Kenaf	BAE Systems	www.baesystems.com
USA	TALON	Foster-Miller/QinetiQ North America , Waltham, Massachusetts.	www.foster-miller.com
USA	TALON SWORDS	Foster-Miller/QinetiQ North America, Waltham, Massachusetts.	www.foster-miller.com
USA	Teledyne Watersabre. Large wheeled explosives defeating UGV.	TELEDYNE BROWN ENGINEERING	www.tbe.com
USA	Teleoperated Ordnance Disposal System (TODS)	Jackson and Tull (formerly OAO Robotics), Washington, District of Columbia.	www.jacksonandtull.com

Country	System Name	Manufacturer	System Website
USA	TerraMax. Large wheeled logistics UGV.	Oshkosh Defense, Oshkosh, Wisconsin	www.oshkoshdefense.com
USA	Terrascout Autonomous Patrol	Carnegie Mellon University, Pittsburgh, Pennsylvania	http://www.frc.ri.cmu.edu/projects/terrascout/index.html
USA	The Robotic Armored Assault System (RAAS)	General Dynamics	http://www.generaldynamics.com/prod_serv/combat/OFW/ofwgraphics_new.htm
USA	Toughbot	Omnitech	www.omnitech.com
USA	UGV	BAE Systems	www.baesystems.com
USA	Unmanned Blackhoe & Unmanned Camera Vehicle	Fujita Research	not found
USA	Unmanned Ground Vehicle (UGV)	Applied Research Associates, Inc	not found
USA	Unmanned Ground Vehicle (UGV) Safe Operations (Safe Ops) T2 using GDRK robotic control technologies. This system can be configured in three options to support: 1) tele-operation, 2) semi-autonomy and 3) full autonomy.	General Dynamics Robotic Systems (GDRS)	http://www.gdrs.com
USA	Unmanned Ground Vehicles	PercepTek, Inc	www.lockheedmartin.com/news/.../1220hq_perceptek.html
USA	Versatrax 100	American Standard Robotics (Inuktun)	http://www.inuktun.com/products-intro.htm
USA	Versatrax 150	American Standard Robotics (Inuktun)	http://www.inuktun.com/products-intro.htm
USA	ZOMBY	Invenscience LC	www.invenscience.com

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